Field Assessment of Soil Cone Index Response to Repeated Wheel Passages on a Trafficability Test Section

Marian Rybansky[1*)], Vit Vozenilek[2,3)], Marian Marschalko[4)]

[1*)] Department of Military Geography and Meteorology, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic, marian.rybansky@unob.cz; ORCID: 0000-0002-3472-1629
[2)] Department of Geoinformatics, Palacky University Olomouc, 17. listopadu 12, 779 00 Olomouc, Czech Republic, vit.vozenilek@upol.cz; ORCID: 0000-0002-4280-1792
[3)] Department of Geoinformatics and Cartography, University of Maria Curie-Sklodowska, al. Krasnicka 2d, 20-718 Lublin, Poland, vit.vozenilek@mail.umcs.pl; ORCID: 0000-0002-4280-1792
[4)] Department of Engineering Geology, VSB – Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava – Poruba, Czech Republic, marian.marschalko@vsb.cz; ORCID: 0000-0001-5612-465X

https://doi.org/10.29227/IM-2026-02-02-053
Submission date: 2026-23-07 | Review date: 2026-07-08

Abstract

Reliable assessment of soil trafficability requires field measurements that account for changes in soil resistance with depth and vehicle loading. This study evaluates the response of the Cone Index (CI) to repeated wheel passages at the U1 field test section using two wheeled vehicles, a TATRA T-815 4×4 and a UAZ 469. Penetration resistance was compared at depths of 60, 100, and 140 mm under three traffic states: before vehicle passage, after the first passage, and after 50 passages. For the TATRA track, CI at 60 mm increased from 2419 kPa before passage to 2723 kPa after one passage and 3156 kPa after 50 passages; at 100 mm, the corresponding values were 3243, 3805, and 3907 kPa. For the UAZ track, CI at 60 mm increased from 2254 to 3186 and 4229 kPa, while at 100 mm it increased from 3188 to 4508 and 4531 kPa. At 140 mm, the final values were nearly identical for the two tracks, reaching 4635 kPa for TATRA and 4643 kPa for UAZ. The largest relative response occurred in the near-surface layer of the UAZ track, where CI at 60 mm increased by 87.6% after 50 passages. In contrast, the differences between the two tracks became substantially smaller with increasing depth. The results demonstrate that the measured penetration resistance was both vehicle- and depth-dependent and that the response after repeated traffic cannot be inferred directly from the first-passage condition. The findings support treating CI as a depth-specific and traffic-state-dependent field variable in trafficability assessment. A pre-passage measurement should therefore not automatically be considered representative of soil conditions after repeated vehicle use.

Keywords: *Cone Index; soil trafficability; penetrometry; repeated wheel passage; soil resistance; off-road vehicles*

1. Introduction

Terrain trafficability is a compound property determined by the interaction of terrain, soil, hydrological and meteorological conditions with the technical characteristics of a vehicle. In military and emergency-response applications, soil is especially important because its resistance to penetration and deformation can change with moisture, structure and repeated loading. Earlier Czech research identified soil characteristics among the principal geographic factors controlling cross-country movement and emphasized that trafficability should be evaluated in relation to the specific vehicle and prevailing environmental conditions [1–3].

Rybansky [4] described soil trafficability as a vehicle–soil problem in which soil type and moisture influence the speed and mobility of off-road vehicles. Subsequent work on cross-country transport modelling showed that geographic factors need to be integrated into a synthetic mobility assessment rather than treated as isolated constraints [5]. The quality of soil and surface information also remains a limiting factor for detailed off-road movement modelling [6]. Recent passability studies similarly combine terrain, soil and other environmental variables to produce vehicle-specific or dynamic trafficability maps [7,8].

Penetrometry is attractive in this context because it provides a direct in-situ indicator of resistance and can resolve changes with depth. A review by O'Sullivan et al. [9] noted that cone penetrometers are useful for field assessment of soil strength, while also stressing that cone index is affected by moisture and structural state and should not be treated as a unique measure of a single intrinsic soil parameter. The relationship between vehicle requirements and soil resistance has also been formalized through the Vehicle Cone Index (*VCI*), which is intended to relate vehicle performance to soft-soil bearing conditions [10].

Recent work by Rybansky et al. [11] further frames penetration testing as a field-deployable basis for ground-bearing-capacity assessment, emphasizing depth-dependent soil strength and the complementary role of static cone and dynamic penetration methods. This supports treating penetrometric values as measurements tied to a defined test procedure and soil state rather than as context-free constants.

Repeated vehicle traffic is relevant because the first passage can modify the soil response measured by a subsequent penetration test. Experimental work using dynamic cone penetration has shown that wheel load, travel conditions and the number of passages can affect soil compaction and the measured cone index [12]. Vehicle-specific trafficability approaches consequently benefit from measurements that distinguish the initial soil state from the state after traffic [13]. At the mapping level, recent studies have also emphasized that trafficability can change dynamically with environmental conditions and therefore requires temporally meaningful input data [14].

The present paper revisits a focused part of an earlier Czech field-testing programme. Its purpose is not to reconstruct the complete trafficability methodology, but to isolate and interpret the penetrometric evidence from one test section U1, for two wheeled vehicles only: TATRA T-815 4×4 and UAZ 469.

The specific objective is to quantify how *CI* changed with depth after the first and fiftieth vehicle passages and to compare the magnitude of the response between the two vehicles. The analysis addresses three questions: (1) how does *CI* at selected depths differ before and after vehicle passage; (2) is the response sustained after repeated passages; and (3) do the two vehicles produce comparable depth-dependent changes in measured soil resistance?

2. Materials and methods

The testing area was located at the left edge of the Podivice village area within the Dedice Military Training Area. The test section was situated near a tank track on a cleared, anthropogenically disturbed handling surface with sparse woody vegetation. The terrain was predominantly level, with a short moderate slope near the edge of the tank track. The surface was covered by dense dry grass.

The source report characterizes the soil as a modal Cambisol influenced by anthropogenic activity and developed on weathered Culm greywacke. In terms of texture, it is described as a medium-heavy loamy soil containing coarse sand and angular gravel. At the time of testing, the soil condition was described as freshly moist to moist. These characteristics are retained because they define the physical setting in which the *CI* measurements were obtained; the results are not intended to provide a generalized characterization of Cambisols.

The vehicle trials were conducted on two parallel wheel tracks. One track was used by the TATRA T-815 4×4 and the adjacent track by the UAZ 469. At the selected measurement locations, penetration resistance was first measured in the undisturbed condition, then after one vehicle passage, and finally after repeated passages along the same track. All vehicle passages were conducted in one direction, and the penetrometric measurements were performed within the corresponding wheel tracks.

A digital RIMIK CP20 cone penetrometer was used for the primary measurements. According to the source report, 212 digital measurement files were obtained, with more than ten recorded values per file on average; eight files were classified as unusable or incomplete. Thus, more than 96% of the measurement files were considered usable in the original processing. Annex 22 of the source report contains the tabulated records used for the present study. The report also states that the measurements were transferred into tabular form and processed using MS Microsoft Excel.

For concise presentation and direct comparison, the present study uses the consolidated U1 values at depths of 60, 100, and 140 mm. Three traffic states are compared: before vehicle passage, after one passage, and after 50 passages. The values are treated as field measurements of penetration resistance under the corresponding test conditions. No attempt is made here to derive the mobility-index parameters described elsewhere in the source report.

2.1. Vehicle characteristics relevant to the field comparison

The technical table in the source report identifies both the TATRA and UAZ vehicles as four-wheel-drive vehicles. The parameters presented below are reproduced only for the two vehicles tested on section U1. They provide the mechanical context for the comparison but are not used to calculate a mobility index in the present study.

Tab. 1. Selected technical parameters of the two vehicles used on section U1, reproduced from the source report.

Vehicle	Operating / total mass (kg)	Engine power (kW)	Specific power (kW/t)	4×4	Wheel width (mm)	No. of wheels
TATRA T-815 4×4 VN	9,200 / 15,000	170	11.3	Yes	380	4
UAZ 469	1,700 / 2,400	53	22.1	Yes*	215	4

*The source table identifies the UAZ configuration as four-wheel drive without differential locks.

2.2. Test variables and evaluation procedure

The principal response variable is the Cone Index (*CI*). Higher *CI* values indicate greater measured resistance to cone penetration at the corresponding depth. For each vehicle and measurement depth, the relative change associated with vehicle passage was calculated as

$$\Delta CI_n\ (\%) = 100 \times (CI_n - CI_0) / CI_0, \tag{1}$$

where CI_0 is the value measured before vehicle passage and CI_n is the value measured after the first or fiftieth passage. This calculation is used only to express the relative magnitude of the observed change and is not interpreted as a universal compaction coefficient.

The analysis deliberately distinguishes between two stages of soil response that can otherwise be conflated in trafficability assessment: the immediate response after the first wheel passage and the response after repeated use of the same track. This distinction is important because penetration resistance varies with depth, whereas wheel loading is transmitted through a finite tyre–soil contact area and may modify the resistance profile differently at different depths.

3. Results

The consolidated results show an increase in *CI* following vehicle passage for both vehicles, although the magnitude of the change varied with vehicle, measurement depth, and number of passages.

Tab. 2. Cone Index values and relative changes at U1 for the two analysed wheeled vehicles.

Vehicle	Depth (mm)	Before (kPa)	1 passage (kPa)	50 passages (kPa)	Δ*CI* 1 (%)	Δ*CI* 50 (%)
TATRA	60	2419	2723	3156	12.6	30.5
TATRA	100	3243	3805	3907	17.3	20.5
TATRA	140	4027	4641	4635	15.2	15.1
UAZ	60	2254	3186	4229	41.3	87.6
UAZ	100	3188	4508	4531	41.4	42.1
UAZ	140	4067	4785	4643	17.7	14.2

3.1. TATRA T-815 response

Before vehicle passage, the TATRA track had *CI* values of 2419, 3243, and 4027 kPa at depths of 60, 100, and 140 mm, respectively (Fig. 1). *CI* therefore increased with measurement depth in the initial condition.

After one passage, *CI* increased to 2723, 3805, and 4641 kPa at 60, 100, and 140 mm, respectively (Fig. 2). Relative to the initial condition, these values correspond to increases of 12.6%, 17.3%, and 15.2%. The largest relative change after the first passage was therefore recorded at 100 mm.

After 50 passages, *CI* values were 3156, 3907, and 4635 kPa at the three respective depths (Fig. 3). Relative to the initial condition, the corresponding increases were 30.5%, 20.5%, and 15.1%. The largest relative change after 50 passages was recorded at 60 mm.

At 140 mm, the *CI* value after the first passage (4641 kPa) was nearly identical to that measured after 50 passages (4635 kPa). In contrast, at 60 mm, *CI* increased from 2723 kPa after the first passage to 3156 kPa after 50 passages. Thus, the additional change between the first and fiftieth passages was more pronounced at the shallower measurement depth.

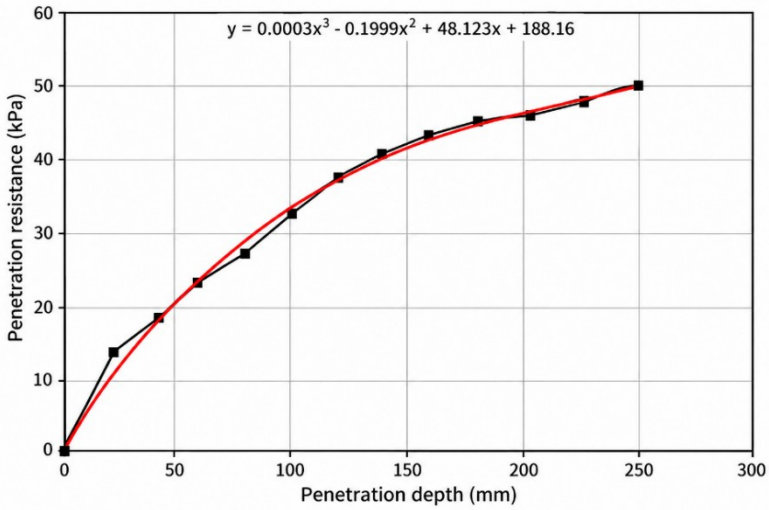

Fig. 1. Relation between penetration resistance and depth for TATRA T-815 4x4 before vehicle passage in Section U1.

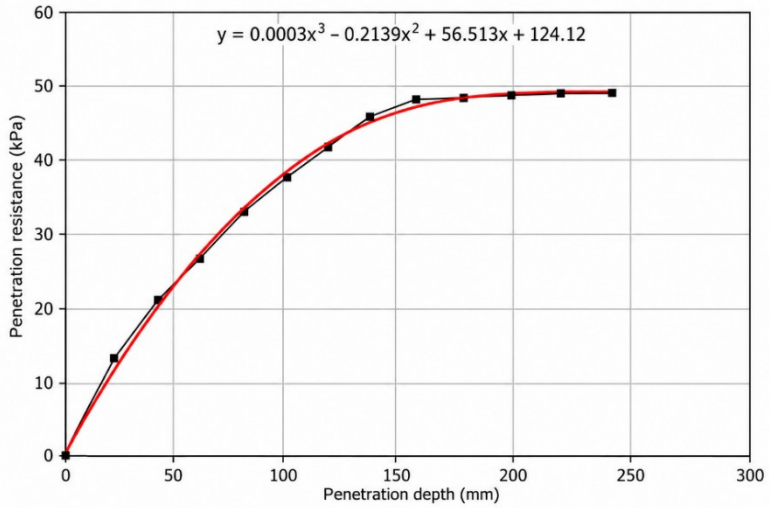

Fig. 2. Relation between penetration resistance and depth for TATRA T-815 4x4 after the first vehicle passage in Section U1.

3.2. TATRA response after repeated passage

The graphical record for the TATRA track after 50 passages is shown in Fig. 3. The profile retained the general pattern of increasing *CI* with depth. The difference between the first-passage and 50-passage conditions was greatest at 60 mm, whereas only a negligible difference was recorded at 140 mm.

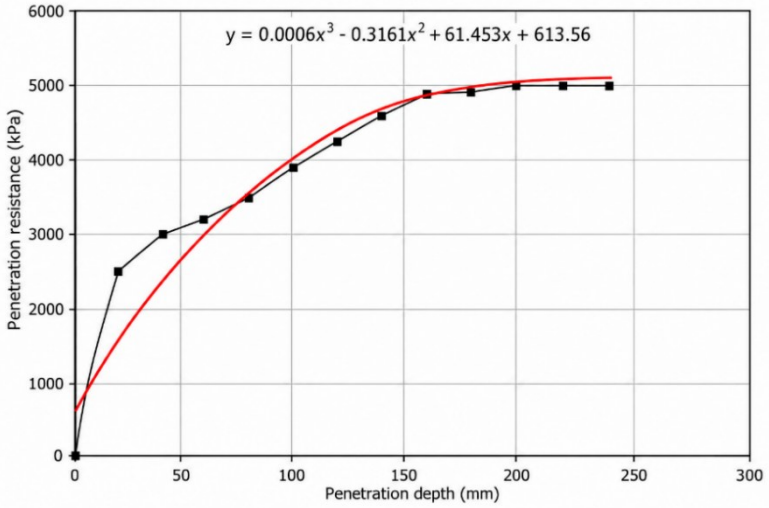

Fig. 3. Relation between penetration resistance and depth for TATRA T-815 4x4 after 50 repeated passages in Section U1.

3.3. UAZ 469 response

Before vehicle passage, the UAZ track had *CI* values of 2254, 3188, and 4067 kPa at depths of 60, 100, and 140 mm, respectively (Fig. 4). As in the TATRA track, *CI* increased with measurement depth in the initial condition.

After one passage, the values increased to 3186, 4508, and 4785 kPa, corresponding to relative increases of 41.3%, 41.4%, and 17.7%, respectively (Fig. 5). The largest immediate relative changes were therefore recorded at 60 and 100 mm.

After 50 passages, the UAZ *CI* values were 4229, 4531, and 4643 kPa at 60, 100, and 140 mm, respectively (Fig. 6). Relative to the initial condition, these values represent increases of 87.6%, 42.1%, and 14.2%. The largest relative change was recorded at 60 mm, where *CI* increased from 2254 to 4229 kPa.

At 100 mm, the value after one passage (4508 kPa) was already close to the value after 50 passages (4531 kPa). At 140 mm, *CI* decreased from 4785 kPa after the first passage to 4643 kPa after 50 passages, although the latter value remained 14.2% above the initial value. Thus, the change in *CI* was not monotonic with passage number at all measurement depths.

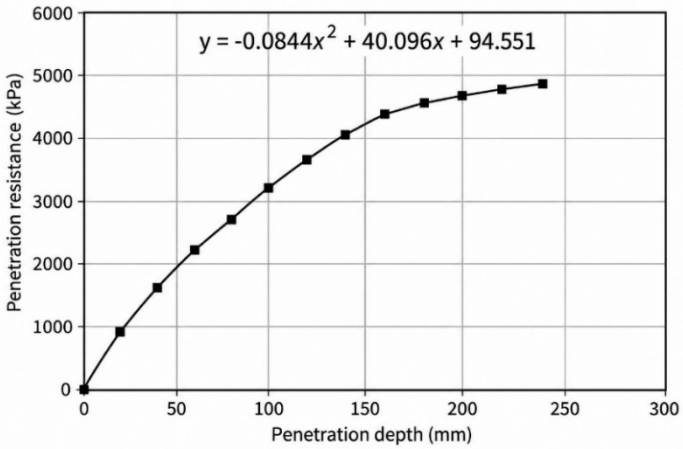

Fig. 4. Relation between penetration resistance and depth for UAZ 469 before vehicle passage in Section U1.

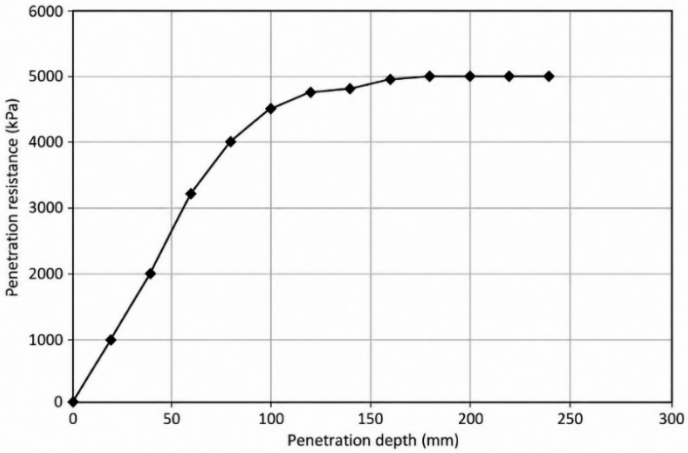

Fig. 5. Relation between penetration resistance and depth for UAZ 469 after the first vehicle passage in Section U1.

3.4. UAZ response after repeated passage

The graphical record for the UAZ track after 50 passages is shown in Fig. 6. The largest change relative to the initial condition occurred at 60 mm. *CI* values at 100 and 140 mm also remained above their respective initial values after 50 passages, but the relative changes were smaller than at 60 mm.

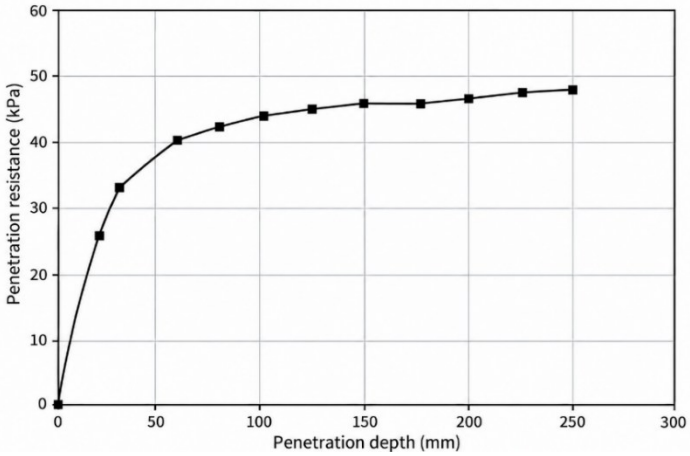

Fig. 6. Relation between penetration resistance and depth for UAZ 469 after 50 repeated passages in Section U1.

3.5. Field photographs of the U1 vehicle tests

The photographs document the field setting and the two parallel vehicle tracks used in the U1 comparison. They are included as source-document illustrations and are not used for quantitative image analysis.

Fig. 7. The vehicle TATRA T-815 4×4 in testing in section U1.

Fig. 8. The vehicle UAZ 469 in testing in section U1.

3.6. Comparative response of the two vehicles

The numerical comparison shows clear differences in the magnitude of the observed *CI* changes between the two vehicle tracks. At 60 mm, the increase after the first passage was 12.6% for TATRA and 41.3% for UAZ. After 50 passages, the corresponding increases relative to the initial condition were 30.5% and 87.6%.

At 100 mm, the first-passage increases were 17.3% for TATRA and 41.4% for UAZ, while the changes after 50 passages were 20.5% and 42.1%, respectively.

At 140 mm, the differences between the two vehicle tracks were considerably smaller. The first-passage increases were 15.2% for TATRA and 17.7% for UAZ, while the corresponding changes after 50 passages were 15.1% and 14.2%. The final *CI* values were 4635 kPa for TATRA and 4643 kPa for UAZ, a difference of only 8 kPa.

The contrast between the two vehicle tracks was therefore greatest at the shallower measurement depths, particularly at 60 mm, whereas the *CI* values measured after 50 passages were almost identical at 140 mm.

The comparison represents an empirical field observation of the two adjacent vehicle tracks. The experimental design does not allow the observed differences to be attributed independently to individual vehicle parameters such as axle load, tyre pressure, tyre–soil contact area, or load distribution.

3.7. Depth-dependent interpretation

The U1 results show a distinct depth-dependent pattern. At 60 mm, the UAZ track exhibited a substantially greater increase in *CI* than the TATRA track, particularly after 50 passages. At 100 mm, much of the final increase was already present after the first passage for both vehicles. At 140 mm, the relative changes were smaller and the final *CI* values of the two tracks were nearly identical.

The measured effect of vehicle passage therefore depended on the depth at which *CI* was evaluated. Comparisons between repeated measurements should consequently be made at consistent measurement depths.

4. Discussion

The results demonstrate the practical importance of distinguishing the initial soil condition from the condition measured after vehicle traffic. Cone penetration measurements characterize resistance at a defined depth and under a particular field state, and repeated wheel passage can alter the subsequently measured resistance within the same track. The direction of change observed at

U1 is consistent with previous experimental work showing that repeated wheel loading can increase penetration resistance, particularly in the shallower part of the soil profile [12]. At the same time, the UAZ results show that the response is not necessarily monotonic with increasing passage number at every depth.

The pronounced near-surface response is also consistent with the known sensitivity of cone resistance to soil moisture and structural condition. Penetration resistance is not an intrinsic material constant; it is influenced by soil texture, density, water content, structure, and measurement-system characteristics [9]. Consequently, the values reported in Table 2 should be interpreted as field-state measurements specific to U1 rather than as transferable material constants applicable to all Cambisols or to all vehicles of the same class.

The comparison also has implications for trafficability modelling. A model based exclusively on an initial soil-strength measurement may not represent the soil condition encountered after repeated vehicle use of the same route. Earlier work on vehicle-mobility modelling emphasized the integration of geographic factors with vehicle-specific characteristics [1,5,6], while more recent approaches incorporate multiple environmental variables and, in some cases, their temporal dynamics [7,8,14]. The U1 results add a field-scale observation to this framework: a soil-strength variable used in trafficability assessment may itself change after vehicle passage.

An important feature of the U1 data is the distinction between the immediate response after the first passage and the condition observed after repeated traffic. The 50-passage state cannot be inferred by simply extrapolating the first-passage change. For TATRA, *CI* at 60 mm increased from 2723 kPa after one passage to 3156 kPa after 50 passages, whereas at 140 mm it changed only from 4641 to 4635 kPa. For UAZ, the corresponding 60-mm value increased from 3186 to 4229 kPa, while at 140 mm it decreased from 4785 to 4643 kPa. The response therefore differed both with depth and with passage state.

The graphical profiles support the same general pattern as the tabulated values: *CI* increased with depth in all measured states, while vehicle passage altered the magnitude and depth distribution of the measured resistance. The figures should therefore be interpreted together with the numerical values rather than as independent evidence.

4.1. Implications for penetration-based trafficability assessment

The findings support three practical principles. First, *CI* should be treated as a depth-specific field measurement rather than as a single undifferentiated value. Second, the traffic state at the time of measurement should be explicitly identified, for example as before passage, after the first passage, or after repeated traffic. Third, comparisons between vehicles should be interpreted cautiously unless the tested tracks are sufficiently comparable and relevant vehicle and soil conditions are controlled or documented.

Repeated-pass experiments are therefore useful even when the ultimate application is a trafficability or passability map. A map derived from a single field campaign represents a particular soil condition, whereas an operational route may subsequently be subjected to repeated loading. Distinguishing between initial and trafficked ground states can improve the interpretation of measured soil strength and can help characterize uncertainty in modelled trafficability.

At the same time, *CI* should not be interpreted independently of soil and measurement context. The U1 site represents a specific field setting described in the source report as anthropogenically influenced, medium-heavy, and containing coarse fragments. Such properties can contribute to spatial variability in penetration resistance. The U1 dataset should therefore be treated as a case study of an observed field response rather than as a universal relationship between *CI* and vehicle performance.

Spatial variability is also relevant when point measurements are transferred to larger terrain units. Samec et al. [15] showed, in a Czech regional study, that soil and bedrock characteristics can vary systematically with regional terrain and geological conditions. Although their study concerns forest soils rather than vehicle trafficability, it provides an additional example of why locally measured soil properties should not automatically be assumed to be spatially uniform beyond the sampled site. Comparable engineering-geological studies have highlighted the importance of local soil properties, site-specific geological heterogeneity, and regional geological variability for the interpretation and spatial extrapolation of field observations [16–18].

4.2. Limitations and scope of inference

Several limitations define the appropriate scope of the conclusions. First, U1 represents a single local soil and surface setting. Second, the two vehicle tracks were adjacent rather than randomly assigned experimental plots; consequently, local differences in texture, coarse-fragment content, initial density, moisture, or other soil properties may have contributed to the observed contrast between the tracks. Third, the consolidated values evaluated here are available only at selected depths and do not support extrapolation beyond the measured profile.

In addition, the available dataset does not isolate the individual mechanical causes of the observed vehicle-specific response. Parameters such as axle load, tyre pressure, tyre–soil contact area, load distribution, and initial soil conditions were not independently varied within a controlled factorial design. The differences observed between the TATRA and UAZ tracks should therefore be interpreted as empirical field responses rather than as effects attributable to any single vehicle parameter.

Fourth, the original research programme included additional vehicles and test sections, but these were deliberately excluded from the present analysis in order to maintain a focused comparison of the TATRA and UAZ vehicles at U1. The present article therefore does not establish vehicle-specific pass/fail thresholds and does not reproduce the Mobility Index (*MI*) or Vehicle Cone Index (*VCI*) calculations included elsewhere in the original research framework.

4.3. Relevance for future field campaigns

Future field campaigns could build on the U1 design by maintaining consistent penetration depths before and after defined numbers of passages while also documenting soil moisture, bulk density, tyre inflation pressure, and vehicle loading conditions at each measurement location. Repeated measurements both along and across the wheel tracks would help distinguish systematic traffic-related changes from natural small-scale spatial variability.

For GIS-based trafficability modelling, the results indicate that soil strength may be represented as a state-dependent variable rather than as an invariant terrain attribute. A practical data structure could therefore distinguish between an initial condition and one or more trafficked conditions. Such an approach is compatible with trafficability models that combine soil, terrain, environmental, and vehicle-related information [5–8,14]. Related engineering-geological and environmental studies also illustrate the broader use of geological, hydrogeological, and anthropogenic information in spatial site assessment, hazard evaluation, and land-use-related applications [19–22].

When such field observations are incorporated into geospatial products, the representation, integration, and comparison of mapped information become additional methodological considerations. Bělka and Voženílek [23] demonstrated the use of georeferenced imagery combined with cartographic symbol layers for communicating geophysical information, while Dvorský et al.

[24] proposed an SVD-based approach for objective comparison of map similarity. At a broader spatial scale, Tuček et al. [25] demonstrated the integration of multiple environmental predictors into classified vulnerability zones. Although these studies do not address wheel–soil interaction or vehicle trafficability directly, they provide relevant methodological precedents for the visualization, integration, and comparison of spatial environmental information in GIS-based trafficability workflows.

The U1 observations further indicate that a single representative depth may be insufficient to characterize the response to repeated traffic. The largest difference between the two vehicle tracks occurred at 60 mm, whereas the *CI* values after 50 passages were nearly identical at 140 mm. A depth-resolved representation therefore preserves information that would be lost if the measured profile were reduced to a single averaged value.

5. Conclusions

The present study evaluated changes in Cone Index (*CI*) at selected depths before vehicle passage, after the first passage, and after 50 passages for two wheeled vehicles tested on section U1. The results demonstrate that the measured soil response depended both on vehicle and on measurement depth, and that the state observed after repeated traffic could differ substantially from the initial condition. Within the limits of the U1 field dataset, the main conclusions are as follows:

1. The U1 field measurements show that vehicle passage measurably changed the Cone Index of the tested soil profile for both TATRA T-815 4×4 and UAZ 469.
2. At 60 mm, TATRA *CI* increased from 2419 kPa before passage to 2723 kPa after one passage and 3156 kPa after 50 passages. UAZ increased from 2254 to 3186 and 4229 kPa, respectively.
3. At 100 mm, TATRA increased from 3243 to 3805 and 3907 kPa, while UAZ increased from 3188 to 4508 and 4531 kPa.
4. At 140 mm, the final values converged: 4635 kPa for TATRA and 4643 kPa for UAZ. The smaller difference at this depth indicates weaker differentiation between the two vehicle tracks than in the near-surface layer.
5. The UAZ track exhibited the largest relative near-surface response, while TATRA showed a more moderate increase. The effect was therefore vehicle- and depth-dependent.
6. For trafficability assessment, the results support recording the traffic state of a test track and maintaining consistent measurement depths. A pre-passage *CI* value should not automatically be assumed to represent the soil after repeated vehicle traffic.

Acknowledgments

This paper is a particular result of the defence research project DZRO VAROPS managed by the University of Defence in Brno and the specific research project 2024–2026 at Department K-210 managed by the University of Defence, Brno.

The authors also thank the VŠB-Technical University of Ostrava, Faculty of Mining and Geology, for supporting the SGS project (SP2025/077 and SP2024/096), within which this article was prepared.

References

1. K. Cibulová, M. Formánek and M. Priesner, “The possible means suggested for improvement of evaluation of low endurable terrain”, in Durability of Critical Infrastructure, Monitoring and Testing (Springer, Singapore, 2017), pp. 17–26. DOI: 10.1007/978-981-10-3247-9_3.
2. W. Dawid, K. Pokonieczny and M. Wyszyński, “The application of the methodology to define terrain passability on a detailed level in various configurations”, Aviation and Security Issues 3(1), 331–352 (2023). DOI: 10.55676/asi.v3i1.61.
3. W. Dawid and K. Pokonieczny, “Generalization of digital elevation models for military passability maps development”, Advances in Cartography and GIScience of the ICA 4, 6 (2023). DOI: 10.5194/ica-adv-4-6-2023.
4. M. Rybansky, “Soil trafficability analysis”, in International Conference on Military Technologies (ICMT 2015) (University of Defence, Brno, 2015), pp. 295–299. DOI: 10.1109/MILTECHS.2015.7153728.
5. M. Rybansky, A. Hofmann, M. Hubacek, V. Kovarik and V. Talhofer, “Modelling of cross-country transport in raster format”, Environmental Earth Sciences 74(10), 7049–7058 (2015). DOI: 10.1007/s12665-015-4759-y.
6. J. Rada, M. Rybansky and F. Dohnal, “The impact of the accuracy of terrain surface data on the navigation of off-road vehicles”, ISPRS International Journal of Geo-Information 10(3), 106 (2021). DOI: 10.3390/ijgi10030106.
7. S. K. Pundir and R. D. Garg, “Development of technique for vehicle specific off-road trafficability assessment using soil cone index, water index, and geospatial data”, Photogrammetric Engineering & Remote Sensing 88(11), 689–697 (2022). DOI: 10.14358/PERS.21-00041R3.
8. I. Potić and D. Đorđević, “Terrain passability modeling for cross-country unmanned ground vehicle navigation”, Transactions in GIS 29(2), e70035 (2025). DOI: 10.1111/tgis.70035.
9. M. F. O'Sullivan, B. C. Ball, A. C. Taylor and A. E. Hunter, “A review of soil strength measurement techniques for prediction of terrain vehicle performance”, Journal of Agricultural Engineering Research 50, 129–155 (1991). DOI: 10.1016/S0021-8634(05)80010-1.
10. J. D. Priddy and W. E. Willoughby, “Clarification of vehicle cone index with reference to mean maximum pressure”, Journal of Terramechanics 43(2), 85–96 (2006). DOI: 10.1016/j.jterra.2004.10.001.
11. M. Rybansky, M. Marschalko and V. Vozenilek, “Use of Penetration Methods for Evaluation of Ground Bearing Capacity”, Inżynieria Mineralna 3(2) (2025). DOI: 10.29227/IM-2025-02-03-46.
12. R. Majdoubi, L. Masmoudi and A. Elharif, “Analysis of soil compaction under different wheel applications using a dynamical cone penetrometer”, Journal of Terramechanics 111, 21–30 (2024). DOI: 10.1016/j.jterra.2023.09.001.

References

13. M. Rybansky and M. Hubáček, "Measuring the influence of soils on the movement of terrain vehicles in the Czech Republic", in Recent Research on Environmental Earth Sciences, Geomorphology, Soil Science and Paleoenvironments (Springer, Cham, 2024), pp. 167–172. DOI: 10.1007/978-3-031-48754-5_39.
14. Q. Liu, X. You, X. Zhang et al., "Construction of dynamic trafficability map for unmanned vehicles considering multiple environmental factors and path planning", Scientific Reports 15, 9957 (2025). DOI: 10.1038/s41598-025-94377-4.
15. P. Samec, V. Vozenilek, A. Vondrakova and J. Macku, "Diversity of forest soils and bedrock in soil regions of the Central-European highlands (Czech Republic)", Catena 160, 95–102 (2018). DOI: 10.1016/j.catena.2017.09.007.
16. M. Marschalko, Z. Zięba, D. Niemiec, D. Neuman, J. Mońka and J. Dąbrowska, "Suitability of Engineering-Geological Environment on the Basis of Its Permeability Coefficient: Four Case Studies of Fine-Grained Soils", Materials 14(21), 6411 (2021). DOI: 10.3390/ma14216411.
17. R. Putiška, M. Marschalko, I. Yilmaz, D. Niemiec, X. Cheng, I. Dostal and J. Kubáč, "Surface Geophysical Methods used to Verify the Karst Geological Structure in the Built-up Area: A Case Study of Specific Engineering-Geological Conditions", Acta Geologica Sinica – English Edition 95(5), 1763–1770 (2021). DOI: 10.1111/1755-6724.14761.
18. M. Marschalko, Z. Zięba, K. Růžičková, J. Růžička, J. Kubáč, J. Dąbrowska, D. Sysala and D. Krčmář, "Small-scale regional engineering geological study of the Czech Republic evaluating the relationship between slope gradients and engineering geological zones", Scientific Reports 14, 5507 (2024). DOI: 10.1038/s41598-024-55972-z.
19. M. Marschalko, I. Yilmaz, V. Křístková, M. Fuka, K. Kubečka, T. Bouchal and M. Bednarik, "Optimization of building site category determination in an undermined area prior to and after exhausting coal seams", International Journal of Rock Mechanics and Mining Sciences 54, 9–18 (2012). DOI: 10.1016/j.ijrmms.2012.05.021.
20. M. Marschalko, I. Yilmaz, D. Lamich and M. Bednarik, "Underground mining hazard map including building site categories in an area affected by underground mining activities", Environmental Earth Sciences 72(7), 2655–2666 (2014). DOI: 10.1007/s12665-014-3172-2.
21. D. Lamich, M. Marschalko, I. Yilmaz, P. Bednářová, D. Niemiec, J. Durďák, K. Kubečka and R. Duda, "Utilization of engineering geology in geo-tourism: few case studies of subsidence influence on historical churches in Ostrava-Karvina District (Czech Republic)", Environmental Earth Sciences 75(2), 128 (2016). DOI: 10.1007/s12665-015-4993-3.
22. D. Krčmář, M. Marschalko, I. Yilmaz, A. Patschová, K. Chalupková and T. Kovács, "Potential pollution risk in natural environment of golf courses: an example from Rusovce (Slovakia)", Environmental Earth Sciences 72(10), 4075–4084 (2014). DOI: 10.1007/s12665-014-3296-4.
23. L. Belka and V. Vozenilek, "Prototypes of Orthoimage Maps as Tools for Geophysical Application", Pure and Applied Geophysics 171(6), 1047–1059 (2014). DOI: 10.1007/s00024-013-0665-y.
24. J. Dvorsky, V. Snasel and V. Vozenilek, "Map Similarity Testing Using Matrix Decomposition", in 2009 International Conference on Intelligent Networking and Collaborative Systems (IEEE, 2009), pp. 290–294. DOI: 10.1109/INCOS.2009.74.
25. P. Tucek, J. Caha, Z. Janoska, A. Vondrakova, P. Samec, J. Bojko and V. Vozenilek, "Forest vulnerability zones in the Czech Republic", Journal of Maps 10(1), 179–182 (2014). DOI: 10.1080/17445647.2013.866911.