

AN ASSESSMENT OF LAND VEHICLES' TRAFFICABILITY

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ABSTRACT

The wide spectrum of vehicles in use by armed forces around the world today can be categorised into two broad categories – wheeled and tracked platforms. Wheeled platforms are generally lighter than their tracked counterparts and are capable of significantly higher on-road speeds that provide better strategic mobility. Although they possess reduced mobility on rough terrains, wheeled platforms' lower acquisition, maintenance and operating costs as well as greater reliability in terms of serviceability make them an attractive option for armed forces. On the other hand, tracked platforms generally offer better soft ground mobility and higher payload capacity for enhanced protection and firepower. However, with today's operations increasingly being executed over less stringent terrains due to rapid urbanisation, soft ground mobility considerations are becoming less critical.

This article quantifies the mobility performance of wheeled and tracked platforms over different operational terrains through the use of terramechanics analysis to better understand the suitability of different platforms for specific combat mission profiles. It also explores possible technologies that would improve soft ground mobility of wheeled armoured vehicles and enhance the ability of armed forces to deploy these platforms across wider mission and terrain profiles.

Keywords: Infantry Fighting Vehicle, terramechanics, mobility

INTRODUCTION

Traditionally, armies looking to increase their combat effectiveness would turn to tracked fighting vehicles as the main weapon-of-choice as they offer better all-terrain mobility, protection and firepower. To possess an equivalent level of combat capability, the mobility of wheeled fighting vehicles would have to be reduced drastically due to the additional weight introduced by armour and weapons systems. Employment of wheeled fighting vehicles in the past have thus been confined to more supportive roles such as providing troop transportation, combat service and combat service support. However, there has been a trend in recent years that calls for the development of expeditionary forces that can be deployed rapidly to deal with regional and international conflicts as well as undertake peace support missions. Armies have thus turned to lighter and more deployable wheeled fighting vehicles with improved protection and firepower. The successful employment of wheeled fighting vehicles in such missions has further fuelled the growing popularity and fielding of wheeled fighting vehicles

to undertake diverse combat roles. As a result, the debate on which is the better land asset – a wheeled fighting vehicle or a tracked fighting vehicle – has resurfaced.

BACKGROUND

Wheeled platforms are able to travel at higher speeds on roads, consume less fuel and cover longer distances by road before they require refuelling. This is due to the lower rolling resistance and reduced frictional losses inherent in wheeled platforms' suspensions and running gear as compared to tracked systems. In addition, wheeled platforms provide a lower noise signature while moving. They also generally do not suffer from excessive vibrations generated by tracks that would affect the operation and reliability of their components and result in crew fatigue. Furthermore, the lower operating costs and better maintainability associated with wheeled platforms reduce its overall life cycle cost.

However, wheeled platforms do have their disadvantages as compared to tracked platforms. In terms of mobility, tracked platforms are a better alternative and are more versatile to operate across diverse terrains, including extremely difficult and soft ground. This is because tracks inherently offer a greater surface contact area than wheels that results in a lower ground pressure. This allows tracked platforms to incorporate other components such as weapon systems and protective armour while maintaining soft ground mobility. Refer to Figure 1 for examples of tracked platforms.

Interestingly, wheeled platforms are increasingly being equipped with levels of protection and firepower comparable to that of a tracked platform. Refer to Figure 2 for examples

of wheeled platforms. This is made possible by trading off soft ground mobility with increased operational capability in less stringent terrains. It is important to note that there is no single criterion which can be applied that will answer the wheeled-versus-tracked debate for all situations and missions. In fact, the underlying premise in resolving this debate is deeply rooted in the complex variables that encompass combat mission, terrain profile and specific vehicular characteristics.

With that in mind, this article aims to quantify the mobility performance of wheeled and tracked platforms across a variety of operational terrains through terramechanics analysis and calculation. Understanding the relative mobility performance of wheeled and tracked platforms over different



(a)



(b)

Figure 1. (a) BMP3 fitted with 30mm cannon, 7.62mm all round and 35mm frontal protection. (© Vovan / File:2008 Moscow May Parade Rehearsal - BMP-3.JPG / Creative Commons / Attribution 3.0 Unported) (b) MLI-84 fitted with 25mm cannon and protection against 12.7mm heavy calibre machine gun. (© Nicubunu / File:MLI-84 IFV on parade.jpg / Creative Commons / Attribution-Share Alike 2.0 Generic)



(a)



(b)

Figure 2. (a) LAV III fitted with a M242 25mm chain gun with TIS and basic STANAG 4569 level III and potential upgrade in protection against 14.5mm rounds with a strengthened bottom for improved protection against landmines and improvised explosive device's blasts. (©Allied Joint Force Command Brunssum / File:Exercise TRIDENT JUNCTURE (21806776594).jpg / Creative Commons / Attribution-Share Alike 2.0 Generic) (b) BTR-4 fitted with a 30mm cannon with protection against 7.62mm ball rounds and artillery shell splinters. It is able to withstand 6kg of anti-tank mine blasts. (© Nickispeaki / File:Українські_KRAZ_Cougar_IMG_7633_01.JPG / Creative Commons / Attribution-Share Alike 4.0 International)

terrains would enable more informed decisions to be made with regard to the suitability of different platforms for specific combat mission profiles. The analysis will focus on comparing wheeled and tracked armoured fighting vehicles, due to the growing popularity of wheeled fighting vehicles that has ignited the wheeled-versus-tracked debate. This article also explores possible technologies that would improve the mobility of wheeled armoured vehicles and allow them to be deployed across wider mission and terrain profiles.

ASSESSMENT METHODOLOGIES

A platform's gross vehicle weight and its footprint are critical in determining the resultant ground pressure that it exerts on the ground. There are several methods available for evaluating off-road vehicle mobility performance. The two commonly used methods are the Waterways Experiment Station (WES) Vehicle Cone Index (VCI) model developed by the US Army Corps of Engineers and the Mean Maximum Pressure (MMP) concept proposed by Roland (1972). The MMP was subsequently supplemented with a new concept – Limiting Cone Index (CI_L) – introduced by Maclaurin (1997).

Waterways Experiment Station Vehicle Cone Index

In the WES VCI model, an empirical equation is established to first calculate the Mobility Index (MI) of a vehicle based on its specific design characteristics. The MI for tracked and wheeled vehicles are calculated using several factors such as contact pressure, weight, track/tyre. The formulas used to calculate the MI for wheeled and tracked platforms are defined in the Appendix.

The VCI represents the minimum strength that the soil needs to possess on its critical layer for the vehicle to successfully make a specific number of passes, usually expressed as single pass or 50 passes. The higher the VCI, or ground pressure, the less mobile the platform becomes. In developing and validating the models, vehicles were tested over a range of terrains, primarily on fine and coarse-grained soils. The values of VCI for single and 50 passes can be derived from the MI values based on the empirical equations developed by Rula and Nuttall (1971). The VCI for tracked platforms can be calculated using the equation:

$$VCI_{Track\ 1} = 7.0 + 0.2MI - \left(\frac{39.2}{MI + 5.6}\right)$$

$$VCI_{Track\ 50} = 19.27 + 0.43MI - \left(\frac{125.79}{MI + 7.08}\right)$$

The VCI for wheeled platforms is calculated using the equation:

$$VCI_{Wheel\ 1} = 11.48 + 0.2MI - \left(\frac{39.2}{MI + 3.74}\right)$$

$$VCI_{Wheel\ 50} = 28.23 + 0.43MI - \left(\frac{92.67}{MI + 3.67}\right)$$

An empirical system using the Rating Cone Index (RCI) was developed by the WES for the measurement of soil strength to assess a platform's trafficability over a terrain. RCI is used to represent the strength of the terrain under repeated vehicular traffic and is defined as the product of the Cone Index (CI) and Remoulding Index (RI). CI is the force per unit cone base area and is used to determine the strength of the soil. It is measured by using a cone penetrometer and RI is a factor that is used to adjust the CI to cater for multiple passes of the vehicle on soil.



Figure 3. Cone Penetrometer (© HPsy / File:Penetrometer.jpg / <https://commons.wikimedia.org/wiki/File:Penetrometer.jpg> / Public Domain)

The cone penetrometer typically comprises a cone of varied degree, steel shaft, proving ring, micrometre dial and handle (see Figure 3). When the cone is forced into the ground, the proving ring is deformed proportionally to the amount of force applied which is indicated on the dial inside the ring. If RCI is greater than VCI, the vehicle will pass; otherwise the vehicle will likely be bogged down.

Mean Maximum Pressure and Limiting Cone Index

MMP is commonly used by the British Army Engineers Corps for the evaluation of vehicle mobility on coherent (clay) soil. A lower value of MMP indicates less sinkage, which means that there is better soil trafficability, movement speed and vehicle mobility. However, MMP alone does not provide quantitative information of a platform's mobility over specific terrain types. This can be supplemented by information provided by the CI_L . The correlation of the MMP and CI_L can be used to determine if the terrain is passable to a particular vehicle. The MMP for tracked vehicles can be calculated using the equation:

$$MMP_{Track} = \frac{1.26W_T}{2nb\sqrt{pd}} [kPa]$$

Where W_T = Vehicle weight (kN)

n = Number of wheels on one track

b = Track width (m)

d = Diameter of wheel (m)

p = Track pitch (m)

The MMP for wheeled vehicles is calculated using the equation:

$$MMP_{Wheeled} = \frac{kW_T}{2mb^{0.85}d^{1.15}\sqrt{\frac{\delta}{h}}} [kPa]$$

Where W_T = Vehicle weight (kN)

k = Axle factor

m = Number of axles

b = Tyre breadth, non-loaded wheel (m)

d = Tyre diameter, non-loaded wheel (m)

h = Tyre height (top of tread to rim)

δ = Tyre deflection due to load

The typical allowable range of MMP for articulated steering on fine grain soils and tropical wet soils is usually between 150kN/m² to 300kN/m² and 90kN/m² to 240kN/m² respectively (Larmine, 1988). In the event that the platform is required to perform skid steering on fine grain soils and tropical wet soils, this range would be more stringent – MMP values are supposed to be within the region of 120kN/m² to 240kN/m² and 72kN/m² to 192kN/m² respectively (Larmine, 1988).

An approximation of the correlation between VCI and MMP, which aids in the assessment of trafficability over terrains of specific CI/RCI, is as follows:

$$VCI_1 = 0.096 \text{ MMP}$$

$$VCI_{50} = 0.27 \text{ MMP}$$

CI_L is the of the weakest soil across which a vehicle can make a single pass. CI_L can be calculated using the equation:

$$CI_{L\text{Wheel}} = \frac{1.85 \times W_w}{2 \times n \times b^{0.8} \times d^{0.8} \times \delta^{0.4}}$$

$$CI_{L\text{Track}} = \frac{1.63 \times W_w}{2 \times n \times b \times e \times p^{0.5} \times d^{0.5}}$$

Where W_w = vehicle weight, kN

n = number of axles, number of road wheels per side

b = (inflated, unloaded) tyre width, track width, m

d = (inflated, unloaded) tyre diameter, m

δ = tyre deflection when loaded, m

p = track plate length, m

e = track link area ratio

The results can be cross-referenced against MMP values to determine if the vehicle is passable on the particular terrain.

Comparison of Methodologies

Both the WES VCI and MMP/CI_L methods aim to determine a vehicle's ability to manoeuvre across various types of terrain. The parameters employed by these two methods show that a platform's surface area of contact with the ground plays a very critical role in its trafficability. The larger surface area of contact afforded by a track thus explains why the tracked platform would have better trafficability than a wheeled platform of equivalent or less weight. The WES VCI methodology provides better resolution for the number of passes that a particular platform can make across a specific terrain compared to the MMP/CI_L method. The WES VCI methodology would thus be more useful when conducting detailed trafficability analysis to determine if a particular platform can be employed for a specific area of operation based on a specific mission profile. It also allows for the exploration of alternative scheme of manoeuvres by spreading out forces to reduce the number of passes that

needs to be made across the same area. MMP/CI_L, on the other hand, provides a simpler comparison and can be used as a first-cut comparison between different platforms.

TRAFFICABILITY COMPARISON BETWEEN SELECTED WHEELED AND TRACKED VEHICLES

Using the above empirical methods, the MI and MMP of selected wheeled and tracked vehicles can be obtained. Their corresponding VCI values are shown in Table 1 for comparison. From the results, it can be concluded that the VCI of wheeled vehicles is approximately 20% to 30% higher than that of tracked vehicles of equivalent weight.

Figure 4 shows the trafficability on low to high moisture sand and clay. It includes the average VCI ranges calculated in Table 1 for tracked and wheeled vehicles.

WV = Wheeled Veh TV=Tracked Veh	Weight of System (kg)	MI	Corresponding		MMP (kPa)
			VCI ₁	VCI ₅₀	
Wheeled Vehicles					
WV1	24,000	100	31	70	246
WV2	25,000	108	33	75	260
WV3	26,000	119	35	78	266
Tracked Vehicles					
TV1	26,000	66	24	55	148
TV2	28,000	77	26	60	165
TV3	29,000	89	29	66	211

Table 1. Comparison of wheeled and tracked vehicles

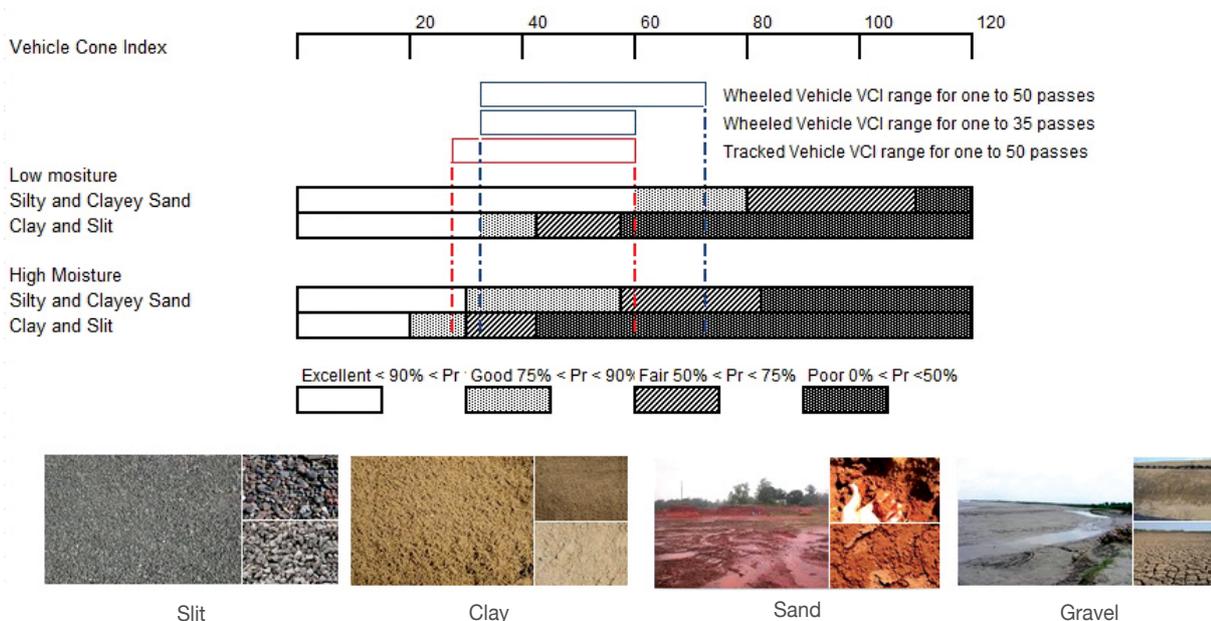


Figure 4. Trafficability of dry, moist, coarse and fine grained sand

From Figure 4, it can be seen that if there is a reduction in the required number of passes for wheeled vehicles of approximately 30%, the probability of traversing the particular terrain of the wheeled vehicle will be comparable to the tracked vehicle, except for softer grounds. This information should be taken into consideration together with the doctrine and operation requirements in deciding the most suitable type of platform. If the number of passes required can be first determined, it is possible to derive the additional payload that a wheeled vehicle can take. This additional payload can be translated into improved firepower or protection.

In addition, there are off-the-shelf products and systems in the market that aim to reduce the ground pressure of vehicles which in turn can be used to increase the number of passes made.

POSSIBLE MOBILITY ENHANCEMENTS FOR WHEELED IFVS

Track Over Wheel Systems

In the construction industry, it is common to improve the traction and mobility of wheeled heavy equipment by introducing a track that wraps round the wheels. This Track Over Wheel (TROW) system increases the surface area of contact between the equipment and the ground as well as the amount of traction it has (see Figure 5). It is important to note that the overall system weight could potentially be about 10% lower than tracked vehicles, and this reduction in weight could be channelled to incorporate weapon systems, protective features or payload capacity. However, such a system has yet to be demonstrated in military vehicles due to complexities in installation and steering.

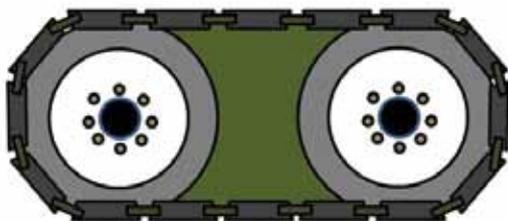


Figure 5. TROW system

Assuming that the TROW system is employed onto an eight-wheel drive with four sets of band tracks, the ground surface area of contact of the platform will likely increase by an estimated 120% to 150%. This will reduce the VCI values by approximately 10% which translates to an additional increase of about three to five passes as compared to the initial assessment.

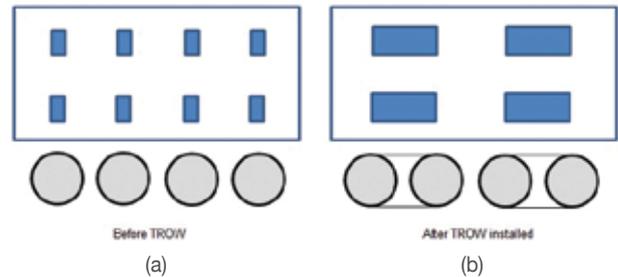


Figure 6. Surface area of contact (a) without the TROW system and (b) with the TROW system

Central Tyre Inflation System

This is the most common system used in not only commercial vehicles, but also military platforms. The Central Tyre Inflation System (CTIS) controls the amount of air pressure in each individual tire of a wheeled vehicle from within the driver's cabin as a means to improve its trafficability. Lowering the air pressure in the tyre directly increases the surface area of contact between the ground and tyre, hence making manoeuvring on terrain with low CI much easier (see Figure 7). In addition, the surface area of contact experiences an increase between 5% and 20%.

Table 2 provides a summary of the two systems that are designed to improve the mobility of wheeled vehicles.

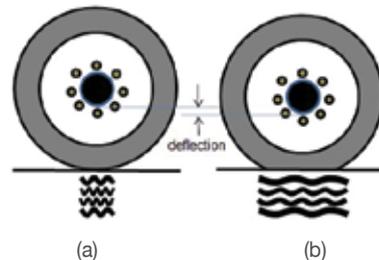


Figure 7. (a) Inflated tyre (b) Deflated tyre

Systems	Advantages	Disadvantages
TROW system	Works almost like a track system	Integration issues
CTIS	Around 10% reduction in MMP/VCI	May not be as significant as other methods

Table 2: Summary of systems to improve wheel vehicles' mobility

CONCLUSION

Wheeled and tracked vehicles each have their advantages which can be further enhanced to meet different operational requirements. Tracked armoured vehicles generally have better soft ground mobility and are optimal for tactical and high mobility roles. They are also best suited for missions requiring unrestricted terrain movement, continuous all-weather operations as well as smaller silhouettes and dimensional envelopes. However, with the increasing urbanisation of the battlefield, wheeled armoured vehicles are finding wider and more front-line combat applications. This has been achieved through advancements in protection technologies and remote control weapon stations that increase a wheeled vehicle's lethality and survivability with lower weight penalty. Coupled with mobility enhancement technologies such as CTIS and TROW, which can increase the surface area of contact and possibly generate greater traction based on the tyre footprint, wheeled armoured vehicles could play a larger role in delivering enhanced combat capabilities to frontline troops.

APPENDIX

MI For Tracked Platforms

$$\text{Mobility Index}_{\text{Track}} = \left\{ \begin{array}{l} \text{Contact Pressure Factor x Weight Factor} \\ \text{Tyre Factor x Grouser Factor} \\ + \text{Bogie Factor - Clearance Factor} \\ \text{x Engine Factor x Transmission Factor} \end{array} \right\}$$

Where

$$\text{Contact Pressure Factor} = \frac{\text{gross weight (in lb)}}{\text{area of tracks in contact with ground (in in}^2\text{)}}$$

$$\text{Weight Factor} = \begin{array}{l} = 1.0 \text{ for } < 50,000 \text{ lb} \\ = 1.2 \text{ for } 50,000 \text{ to } 69,999 \text{ lb} \\ = 1.4 \text{ for } 70,000 \text{ to } 99,999 \text{ lb} \\ = 1.8 \text{ for } > 100,000 \text{ lb} \end{array}$$

$$\text{Track Factor} = \frac{\text{track width (in inch)}}{100}$$

$$\text{Grouser Factor} = \begin{array}{l} = 1.0 \text{ for } \text{grousers } < 1.5 \text{ in} \\ = 1.1 \text{ for } \text{grousers } > 1.5 \text{ in} \end{array}$$

$$\text{Bogie Factor} = \frac{\text{gross weight (in lb) divide by 10}}{\left(\frac{\text{No. of bogies on tracks}}{\text{Contact with ground}} \right) \times \left(\frac{\text{area (in in}^2\text{) of 1}}{\text{track shoe}} \right)}$$

$$\text{Clearance Factor} = \frac{\text{clearance (in inch)}}{10}$$

$$\text{Engine Factor} = \begin{array}{l} = 1.00 \text{ for } > 10 \text{ hp/ton of vehicle weight} \\ = 1.05 \text{ for } > 10 \text{ hp/ton of vehicle weight} \end{array}$$

$$\text{Transmission Factor} = \begin{array}{l} = 1.00 \text{ for automatic transmission} \\ = 1.05 \text{ for manual transmission} \end{array}$$

MI for Wheeled Platforms

$$\text{Mobility Index}_{\text{Wheel}} = \left\{ \begin{array}{l} \text{Contact Pressure Factor x Weight Factor} \\ \text{Tyre Factor x Grouser Factor} \\ + \text{Wheel Load Factor - Clearance Factor} \\ \text{x Engine Factor x Transmission Factor} \end{array} \right\}$$

Where

$$\text{Contact Pressure Factor} = \frac{\text{gross weight (in lb)}}{\left(\frac{\text{Tyre section}}{\text{Width (in inch)}} \right) \times \left(\frac{\text{outside radius}}{\text{of tyre (in inch)}} \right) \times \left(\frac{\text{no. of}}{\text{tyres}} \right)}$$

$$\text{Weight Factor} = \begin{array}{l} \text{Required Weight*} \\ 0.553 \text{ Q}^{**} \text{ for } < 2,000 \text{ lb} \\ 0.033 \text{ Q}^{**} + 1.05 \text{ for } 2,000 \text{ to } 13,500 \text{ lb} \\ 0.142 \text{ Q}^{**} - 0.42 \text{ for } 13,501 \text{ to } 20,000 \text{ lb} \\ 0.278 \text{ Q}^{**} - 3.115 \text{ for } > 20,000 \text{ lb} \end{array}$$

$$**\text{Q} = \frac{\text{gross weight (in lb)}}{1000 \times \text{no. of axles}} \quad * \frac{\text{gross weight (in lb)}}{\text{no. of axles}}$$

$$\text{Grouser Factor} = \begin{array}{l} = 1.05, \text{ with chains} \\ = 1.00, \text{ without chains} \end{array}$$

$$\text{Tyre Factor} = \frac{10 + \text{tyre width (in inch)}}{100}$$

$$\text{Wheel Load Factor} = \frac{\text{gross weight (in lb)}}{1000 \times (\text{no. of axles}/2)}$$

$$\text{Clearance Factor} = \frac{\text{clearance (in inch)}}{10}$$

$$\text{Engine Factor} = \begin{array}{l} = 1.00 \text{ for } > 10 \text{ hp/ton of vehicle weight} \\ = 1.05 \text{ for } > 10 \text{ hp/ton of vehicle weight} \end{array}$$

$$\text{Transmission Factor} = \begin{array}{l} = 1.00 \text{ for automatic transmission} \\ = 1.05 \text{ for manual transmission} \end{array}$$

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BIOGRAPHY



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