Introduction to

Mine Clearing Technology

ABSTRACT

This paper presents the technologies and methods developed for mine clearing operations currently used by the military and humanitarian demining organisations. In any mine clearing operation, the operating environment and the type of threats are never the same. Thus, a single method or type of equipment rarely constitutes the most successful means of resolving the problem in terms of time, cost and effectiveness; a combination of tools is more commonly employed to ensure a successful mine clearing mission. This paper aims to give an introduction to and appreciation of the key mine clearing methods and equipment, and the key differences and considerations for military and humanitarian operations. The common methods of demining such as manual demining, explosive mine breaching and mechanical demining will be discussed. The design considerations for mine flails on mine clearing vehicles will also be presented.

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INTRODUCTION

History of Mines

Mines, derived from the Latin word 'Mina' meaning 'vein of ore' was originally used to describe the digging of minerals from the earth. Over time, it has become a term used by military engineers to denote the explosives they lay in the ground during battles.

Mines were first used in third B.C. in the form of non-explosive metal spikes laid in the earth as a form of defensive tactics. In the 14th century, the world ushered in the arrival of explosive mines which are commonly found even in modern times. The basic design of the mines was usually simple explosive matter buried with debris or metallic pieces that were to be used as fragments during an explosion.

Mines became a regular feature of warfare only in the 19th century. It was in 1918 that mines first became used on a large scale as an effective means against the assault tanks introduced then.

Since then, mines have become a new threat in war, which also meant that a solution had to be developed against them. Thus, this sparked the development of various mine clearing techniques.

NEED FOR MINE CLEARING

By World War Two (WWII), mines had evolved to perform two major functions: to kill and maim personnel, or to destroy and disable tanks and vehicles. The US Army recorded that 2.5% of fatalities and approximately 21% of tank losses of WWII were mine-related.

In addition to WWII mines, an estimated 400 million mines have been laid in various conflict areas since then.

Despite the initial development of mine clearing concepts as a form of countermeasure against mines during wartime, the real need for mine clearing usually begins after the end of hostilities. This is attributed to the very nature of why mines were laid in the first place – to deter access to and use of land. Mines laid during conflicts are rarely removed at the end of the conflicts due to the lack of proper mine maps, markings, loss of such maps and markings or changes in mine location due to soil shifts. Unlike soldiers, mines do not recognise ceasefires and treaties or differentiate between friends, foes or civilians. Mines continue to do their job even years after the end of a conflict.

To this day, there are up to 65 countries still afflicted by mine threats from past conflicts, with the worst regions being Angola, Namibia, Mozambique, Somalia, Ethiopia, Eritea, Sudan, Croatia, Iraq, Afghanistan, Russia, Cambodia and Vietnam. On average, there are approximately 70 injuries and death from mines every day. It is this threat posed by mines that places extreme risks on the civilian population who return to the land after a conflict.

The problems caused by active minefields do not end here. There are also socioeconomic effects as fertile lands are not available for agriculture, roads are not accessible and land cannot be cleared for industries. These eventually lead to continued poverty and famine in the affected areas. Thus, despite the high cost of humanitarian demining efforts, Mine Action Co-ordination Centres supported either by the United Nations (UN) or host countries have been set up in different countries to drive the demining efforts.

TYPES OF MINE CLEARING METHODS AND EQUIPMENT

The estimated cost of clearing a mined area of one square kilometre is about US$1 million, whereas it takes only a few dollars to acquire a mine. Thus, the search has always been ongoing to find a more effective solution for mine clearing. In this section, the types of mine clearing methods and equipment will be discussed.

Manual Demining

Manual demining is the most commonly used means in humanitarian demining. It is also the only recognised method of demining that is able to achieve the 99.6% clearance rate required by UN standards. Its main function is to detect and locate mine locations for deactivation or destruction in the later stages. It consists of the use of manual prodding methods, use of detectors such as metallic detectors and even animals.

Figure 1. Manual deminer with body armour using prodding tool

As the name suggests, this is also the most labour-intensive and costly method which requires a large amount of human effort and specialised training. In the case of manual prodding and metal detection, large numbers of people from the local population are employed to work through a selected piece of land with personnel protection kits and selected tools (see Figure 1). Although the method is effective, it is one of the slowest ways of clearing a piece of land. The progress of demining is either hampered by high false alarm rates due to instances of metallic objects in the ground or by deeply placed metal mines which are hard to detect. Recent developments include the introduction of Ground Penetrating Radars. Although more effective, the technology has its fair share of drawbacks in terms of high false alarm rates.

Manual demining also creates a socioeconomic benefit for the population of the area as it creates a large number of jobs for people who are usually living below the poverty line. These jobs eventually enable the local population to slowly rebuild their lives.

In the case of mine detection using animals such as dogs and rats (see Figure 2), the animals are carefully trained to detect the explosive

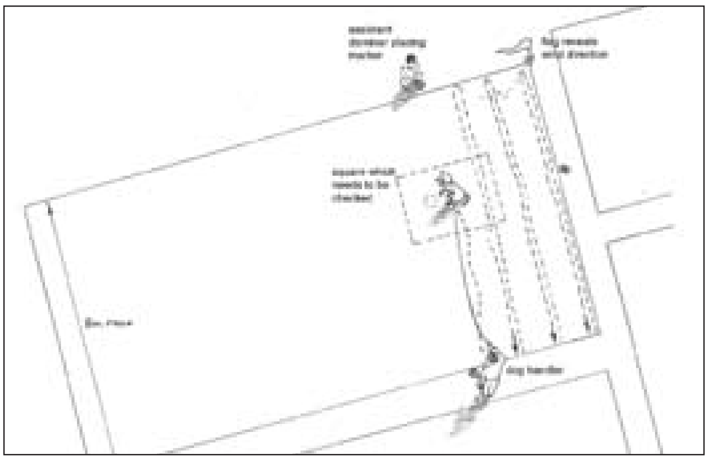

Figure 2. How a mine dog is deployed to detect mines

substances from the mines (RDX[1] or TNT) and to react in a prescribed manner when they pinpoint the location of the mine. The effectiveness of using animals is limited by the training they undergo and the duration they can be deployed in the field. Without sufficient training, the effectiveness of the method can be greatly reduced. Effectiveness is also reduced if the animal is deployed in the field for too long, as fatigue may also affect its ability to detect.

Use of Explosive Charges in Demining

In essence, the use of explosive charges in demining is usually limited to the destruction of the mines after they have been detected through more traditional means such as manual demining.

But in the arena of military operations, it provides a fast and effective way to create a path for vehicles or men through a minefield. This is often referred to as 'breaching'.

The main underlying concept of this method is the deliberate triggering or destruction of mines within the section route or area through the introduction of massive blast waves created by an explosion. The same blast wave will also act to trigger any Improvised Explosive Devices (IED) within the selected area.

Although the same concept is employed, different types of equipment have been developed to create this capability. What differentiates them from one another is usually the breadth and length of the cleared path that is created. Some more common forms of explosive charges used are bangalore torpedoes, man-carried or vehicle-mounted line charges (see Figure 3). The more modern approach would be the use of vehicle-launched fuel-air explosive bombs.

Figure 3. A Cobra Projection Line charge used by combat engineers

Mechanical Demining

Mechanical demining methods deployed since World War One (WWI) includes the use of tiller systems, mine rollers, mechanical excavation, mineploughs and mine flails. Although the main concepts have not changed much over the years, the technology behind them has. Recent developments on mechanical demining include the use of remote control systems which allows remote operations of the equipment from as far as 5km away. Additional armour to protect the operator cabin, improved cabin designs to improve crew survivability and system designs to overcome the traditional limitations of mechanical demining methods have also been developed.

Although developed initially for military operations, some mechanical demining methods have been used in humanitarian demining operations. The advantage of using mechanical demining methods for humanitarian purposes is the ability to clear large amounts of land quickly. However, there are doubts on its effectiveness and ability to achieve the 99.6%[2] clearance rate required. Thus, a secondary method is usually employed to validate the cleared land. The following section will briefly describe the functions and design of each mechanical demining method.

Figure 4. The tiller drums of the Rhino system

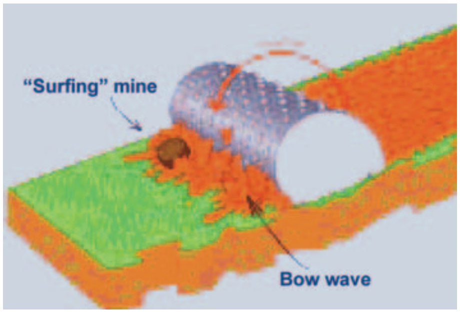

Figure 5. An example of a mine "surfing" on the bow wave

Tiller Systems

Tiller systems (see Figure 4) are generally purpose-built systems designed for destroying mines or Unexploded Ordnance (UXO). Due to the nature of their operations, they are usually heavy and large in size. Substantial power is required to operate the heavy tiller drum as well as the prime mover, which is most likely a tracked vehicle. The tiller system employs the use of rotation drums fitted with overlapped teeth or bits that would grind up the ground in accordance with the depth they are required to dig. Mines or UXOs would either be destroyed or activated through direct contact with the teeth of the rotating drums.

Key issues with the tiller system are the possibility of burying the mines deeper below the tiller due to the downward force of the drum and the collection of mines in the 'bow wave' (see Figure 5). The bow wave is the collection of loose soil in front of the drum caused by the forward movement of the drum. The tiller system has also been reported to have lower effectiveness in soft and rock-stewed soil.

Anti-Mine Rollers

One of the older mechanical demining methods, the anti-mine roller was first deployed in 1914 on the British tanks. It has been adapted for humanitarian purposes over the years.

Although a typical anti-mine roller would be mounted on a modified tractor or wheel loader and made to run over selected areas to deliberately activate mines that are live and in serviceable conditions, most anti-mine rollers used in humanitarian demining are not capable of surviving an anti-tank mine blast. As such, careful surveying of the ground is necessary prior to their application. A key issue with the mine roller is its inability to deal with unserviceable and serviceable mines that might be buried too deep.

Figure 6. M1AI equipped with mine roller

Figure 7. The Hydrema M1100 excavator with an armoured cabin which can be attached with different tools for mechanical demining

Figure 8. A mechanical sifter which can be attached to a commercial mechanical demining machine

Mechanical Excavation

Mechanical demining employs the use of various machines to enable the removal of soil from suspected areas for inspection of mines and UXOs. Soil is sent for processing via sifting, manual inspection or crushing to identify unexploded ordnance, which in turn will be sent for disposal by the Explosive Ordnance Disposal (EOD). This method enables soil to be cleared to depths that may not be reachable by tillers, flails and mine rollers.

Equipment used in mechanical excavation is typically construction machines installed with mine blast protection and additional armour in the cabin to protect the operator. Such equipment includes tractors, front-end loaders, bulldozers, excavators and soil sifters. In order to further protect the equipment, larger UXO or anti-tank mines are identified by metal detectors for separate disposal.

To date, there is no known critical drawback of the method as long as appropriate safety measures are taken.

Mineploughs

Similar to anti-mine rollers, mineploughs originated from military applications. One of the earliest applications of mineploughs was in WWII where they were mounted on Churchill and Sherman tanks as part of the assault on Normandy. The mineplough was used as a ‘softer’ approach to mine clearing as unlike the flail, it does not create large columns of dust and craters from destroyed mines. The mineplough works by moving a specially designed shovel just below the surface of the soil in order to plough up mines and push them to the sides of the path created.

The concept of employing the mineplough in front of an armoured vehicle has not changed over the years. As it is still a quick and effective solution for creating a vehicular path across a deep minefield, many variants of modern-day main battle tanks (MBT) are still fitted with the mineplough system.

Today, the depth of clearance can be varied through hydraulic controls and vehicles can be operated remotely increasing the safety level for the operator. One of the most widely used mineplough systems today is the Pearson Full Width Mineplough system which can be easily adapted to various platforms without extensive modifications.

Figure 9. A Bullshorn mineplough mounted on a WWII Sherman Tank

Figure 10. The mine clearing vehicle (Hydrema MCV 910 Series 2)
Source: Army news (April/May 2006)

Figure 11. Tracked Mine Flail System

The key issue with the mineplough is the possible collection of mines that are pushed to the sides of the path. As the mines are rarely activated by the mineplough, secondary means of ordnance disposal must still be in place and thus, the mineplough has not been adapted for humanitarian uses.

Mine Flails

Mine flails were also first developed for military applications and were famously used in WWII where they were fitted on Sherman tanks. The Sherman tank flails are known to be very effective and played an integral role in the initial shore invasion in Normandy.

With the growth of humanitarian demining in the 1990s, flail systems were developed to meet the demand for tools against mines and small UXOs. In the Singapore Armed Forces (SAF), the Hydrema MCV 910 Series 2 has been in service since 2005. The SAF, DSTA and Singapore Technologies Kinetics have jointly developed and built a Tracked Mine Flail which offers more protection to the crew and exceptional mobility performance over other commercial off-the-shelf mine clearing vehicles. The Tracked Mine Flail features a fully automatic deployable flail system and the world's first hydrostatic tank transmission for both creep and normal mobility.

Conceptually, most flail systems utilise the same concept: a drive system, an extended arm, a rotating drum and chains with weights at the ends to provide the pounding force. The force of the swinging hammer is transferred onto the ground upon impact. It is this same impact force that either causes the mine to detonate or shatter.

Each flail system is different in terms of clearing speed, clearing depth, survivability and clearing effectiveness. The next section will cover an in-depth discussion of the design considerations for mine flail systems.

DESIGN CONSIDERATIONS FOR MINE FLAIL SYSTEMS

The key components in the design of mine flail systems are as seen below:

Blast Protection

Blast Shield

Modern mine flails operate with the flail in front of a blast plate system. This blast plate deflects the blast wave and also acts as a protective layer between the mine explosion and the operator. In some cases, the blast shield covers the flail circumference to also prevent throw-out of mines that are not destroyed by the initial impact of the flails.

Blast shield strength and thickness are mainly determined by the threat the flail is designed to meet and the blast shield's angle of inclination. Finite Element Method studies are made in accordance with the expected threat i.e. amount of explosives in the mines and quantity of mines to defeat before inspection and repair to determine if blast shield designs can cope with the blast pressure and fragmentation damage. Actual blast trials are conducted to verify and correlate the stresses on the blast shields with the theoretical results.

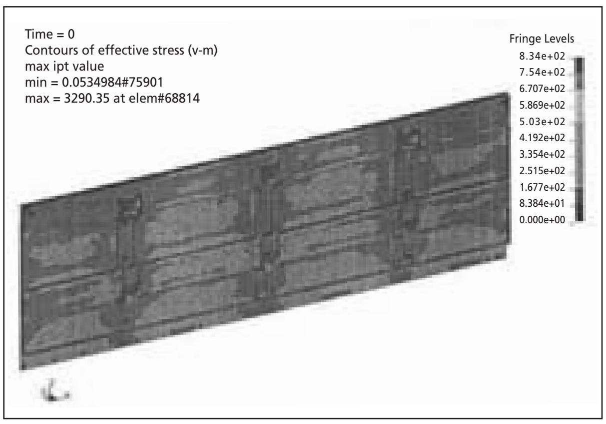

Figure 12. A Finite Element Method study made on a blast load case on a blast shield design

Figure 13. Fragmentation damage from an anti-tank mine with 4.45kg TNT

Figure 14. The blast shield from the Hydrema 910 Series 2 – the flexible flap at the top of the shield deflects the blast wave over the cab without sustaining damage from the blast wave. In addition, the tilted angle of the flap helps to recirculate dust in blast shield during flailing operations.

Protection of the Cabin Against Anti-Tank Mine Fragments

Although the blast effect of a mine is supposed to be contained by the blast shield, there is always a risk of the vehicle going over a missed mine. In order to protect the operator from possible fragmentations in a mine explosion, the cabin is required to be suitably armoured for crew protection.

Protection against Loss of Structural Integrity and Lift

The impact of the blast overpressure affects the platform in two different situations. One is during the detonation of mines by the flail and the other during the detonation of missed mines under either one of the wheels or tracks.

It is extremely important to ensure the structural integrity of a vehicle against mine attacks. When a mine detonates under the vehicle and should the vehicle belly rupture, the blast energy from the mine explosion would cause an overpressure in the cabin. The sudden surge of pressure would injure the unprotected ear and other gas-filled organs e.g. lungs of the operator. The physical limits for overpressure are 200Pa for the ears and 19KPa for the lungs and intestines.

Therefore, to protect the vehicle from mine attacks, forces from the mine blast energy should either be deflected or absorbed to protect the vehicle belly from being ruptured especially at the weld joints. To deflect the forces, a V-shaped hull design can be used such that impact forces are deflected off the sides of the undercarriage of the hull. To absorb the forces, a deflection budget or a sacrificial blast shield can be designed into the hull such that the forces are intentionally absorbed without causing damage to the main hull. In these cases, the deflection budget and the blast shield are usually designed such that they can be easily replaced.

The usage of V-shaped hull design, deflection budget and blast shields are also design features that prevent 'lift' i.e. overpressure forces that act on the impact point causing the vehicle to be lifted off the ground. The sudden lifting of the vehicle can lead to acceleration-related injuries on the foot, ankle and spinal cord of the operators. In severe cases, it may flip the entire vehicle.

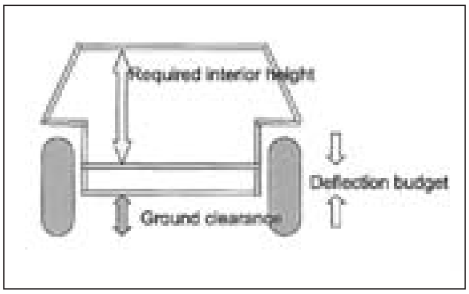

Figure 15. An example of a deflection budget

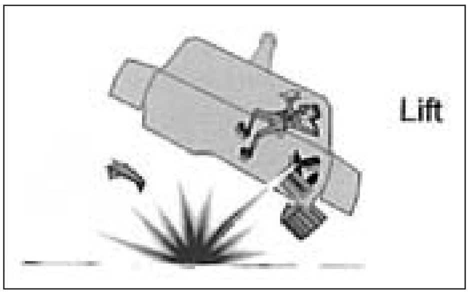

Figure 16. How lift affects a vehicle

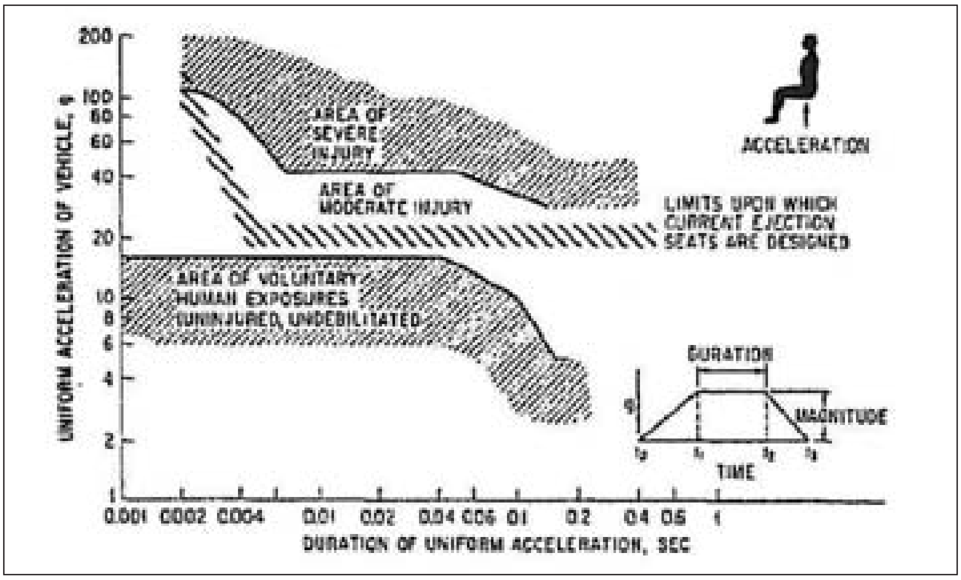

Figure 17. The limits of acceleration exposure prior to injury

Flail System

In our technical evaluation of mine clearing vehicles and the Design Test and Evaluation of the Tracked Mine Flail, we conclude that there are basically four modes by which a mine flail can neutralise the mines. This was derived from extensive testing of the mine clearing vehicles in various terrain and conditions.

In the simplest mode, the chains and strikers (or hammers and weights) of the flail strike the activating plate of the mine and detonate the mine. Mine flails have a typical strike force of more than 1,000kg and it is more than sufficient to set off the mines which typically require 150kg to 200kg. However, when a mine detonates under the flail, there may be damage to the flail system and immediate repairs are required before further operations.

In the second mode, given the strong strike force and intensity of newer flail systems, the mines can be smashed into pieces. This is the desirable mode of defeating the mines as the least damage will be inflicted on the flail system. However, the debris which consists of explosives and detonators can still be a threat to unprotected personnel.

In the third mode, the mines are partially damaged but not smashed in the less drastic cases. The chances of damaging the firing mechanism when the mines are partially damaged are very high. Such mines are also considered neutralised as they cannot deliver the full impact of the charges.

Lastly, the flailing is essentially a digging operation and mines may get thrown up during flailing. However, only mines thrown off the path of the flailing are considered neutralised.

The modes of neutralising the mines are also dependent on the types of mines. For single impulse actuated mines which were commonly used during WWII, the flail is capable of detonating them. For newer anti-shock and anti-flail resistant mines, the other three modes i.e. destruction, neutralisation and throwing off are more common.

There have been limited studies made on the relation between flail effectiveness and ground conditions. Thus, when an area is set to be cleared, it is compulsory for flail operators to perform a test flail to determine the settings of the system. Through comparison of test results from local trials, Swedish EOD & Demining Center and Croatia Mine Action Center reports, DSTA engineers derived that the effectiveness of the flail is a function of the power pack output, flail width, ground condition and creep speed i.e. speed of vehicle movement during flailing. The powerpack needs to be suitably sized in accordance with the flail width required. Generally, the acceptable power output to flail width ratio is between 50HP to 60HP per metre of flail width.

In a given test environment, where the ground conditions are unknown, a test flail must be performed to obtain the creep speed for optimal flail performance. The depth of the flailing is measured to ensure that there is sufficient dig depth to defeat the mines. In our local trials, extensive testing using the MCV to determine the optimum flailing performance on different types of terrain was conducted. With this relationship between flail performance and terrain established from our trials, we can calculate and estimate the performance of other mine clearing equipment without local testing and this saves considerable time and cost during the evaluation of this equipment.

Other Enhancements

Additional enhancement systems are available to improve the operating capability of the flail system. They are as follows:

- **Lane marking system** allows marking out of flail path to demarcate safe zones to travel in. This is more commonly used as a military application in breaching operations.

- **Remote control system** allows the remote control of the entire system from as far as a five-kilometre line of sight. This enables the operator to operate in high-risk situations without endangering his life.

- **GPS position logging systems** log the path cleared by the flail system. The same data can be transferred to a digital map for confirmation of the areas that have been cleared.

Figure 18. A German Parm 1 off-route mine

Challenges for Mechanical Mine Clearing Systems

Although a large number of mechanical mine clearing systems has been developed to improve the process of demining, many available systems are still unable to cope with the following challenges:

- **Steep, undulating terrain** – As mechanical demining requires ground contact to be effective, the presence of undulating terrain can cause 'skip zones' where either insufficient pressure or impact was applied onto the ground. These skip zones remain as potential mined spots within a cleared area unless a secondary means is used to validate the land.

- **Defective mines/mines with delay charges** – The risk comes when the mine does not detonate during the initial contact with the mechanical demining system. The detonation may only be activated seconds later or when the wheel/track pressure is exerted on the mines. This places the operator in danger as the blast detonation may only come after the passing of the blast shield.

- **Shaped charge mines** – Unlike normal mines which cause damage through the transfer of overpressure forces and fragments, shaped charges mines have the capability of piercing through the majority of the armour protection on mine clearing platforms.

- **Slow clearing speed** – For military application, the slow rate of clearance via most mechanical means (except mineploughing) means that the system is often exposed to enemy fire.

- **Intelligent mines** – In military applications, a mine field may not just be filled by conventional mines that are detonated via pressure or magnetic means. There are intelligent mines such as off-route mines which use thermal, seismic, or magnetic sensors or a pressure sensitive wire laid across the road to detect vehicle movement. Once a vehicle is detected, a rocket or other ammunition hidden alongside the road is fired at the vehicles. The more advanced versions can not only differentiate between a tank or other class of armored vehicle, but can even decipher friend from foe as well as between models such as the T-80 and T-72 MBTs. With ranges up to 100m, mechanical demining tools would have little or no protection against them.

CONCLUSION

This paper has discussed the different tools and concepts employed for demining. Despite the wide variety of equipment developed against mine threats, there is no single method or tool that is truly a perfect match for all situations. Careful surveying and situational assessment are still required to determine the most effective solution for each situation. Further improvement of existing tools might be a way forward but the cost of doing so may simply be beyond the means of those who need them. The collaboration of two or more independent tools, each operating using its distinct detection and clearing method, might be a better and cost-effective solution to achieve a more thorough mine clearing performance in the long run.

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ENDNOTES

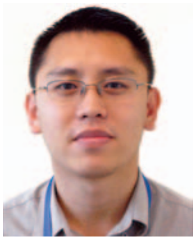
[1] RDX (Cyclotrimethylenetrinitramine) and TNT (Cyclotrimethylenetrinitramine) are explosive substances widely used in military and industrial applications.

[2] All UN-sponsored clearance programmes require the contractor to achieve the agreed standard of mine clearance of 99.6% to a depth of 200mm.

BIOGRAPHY

Tan Chun is a Principal Engineer and Programme Manager (Land Systems). He has many years of experience in managing projects in the areas of military bridges, mine clearing vehicles, engineering plants and light sea vessels. He obtained his Bachelor degree in Mechanical Engineering from the National University of Singapore (NUS) in 1993. In 2001, he obtained a Master of Science in Military Vehicle Technology from the Royal Military College of Science, United Kingdom.

Gary Wong Hock Lye is a Senior Engineer (Land Systems). He is currently involved in the acquisition management of combat engineer systems for the Army. Gary is also involved in the development of mine clearing vehicles. He graduated with a Bachelor degree in Mechanical Engineering in 1999 and obtained a Master of Engineering in 2002 from NUS, with the area of research in characterisation and synthesis of functional materials.



Bryan Soh Chee Weng is an Engineer (Land Systems). Currently he is involved in the acquisition management of combat engineer systems for the Army. He graduated with a Bachelor degree in Mechanical Engineering in 2004 from NUS under the Singapore Armed Forces Local Study Award. Between 2004 to 2007, he served as a Military Engineering Officer in the army as a regular officer.