EXECUTIVE SUMMARY

1. INTRODUCTION

The Cambodian problem of landmines and UXO has been the direct result of decades of wars and conflicts which have devastated the country in every sense. Today, the people of Cambodia have to deal with one of the worst impacts of mines and UXO contamination on the surface of the globe. In the course of these conflicts, each warring faction has polluted indiscriminately and scattered without record or regard to later consequence their killing tools of mines and unexploded ordinances (UXOs). It has been estimated that between 4 to 6 million landmines have been laid - the frightening statistics of one landmine for every two rural Cambodians. In addition, there are the UXOs - the remains of the massive air bombing campaign, and the ordinance that litters the many battlefronts, which are part of the two to three million tons of ammunition expended from 1970 to 1997.

Dealing with these landmines and UXO requires patience, expertise, vast financial resources and advanced technology. As a leading national demining organization in Cambodia, and one of the leading demining organizations worldwide, the Cambodian Mine Action Centre (CMAC) has taken every effort to increase its productivity and improve its efficiency. As mine action evolves and technology advances, CMAC continues to make enormous efforts to carry out research and development of demining related equipment. The successful introduction and application of the mechanical brush cutters, procured in three phases under the Japanese grant aid scheme, is the evidence of success so far in its R&D activities. The application of these machines in the minefields has resulted in a significant increase in clearance productivity.

As part of the continuous effort by CMAC to improve its demining technology, and as a manifestation by the Japanese Government to continue to support mine action in Cambodia and promote research and development of demining related technology, on 17 March 2006 the Government of Japan and the Government of Cambodia signed an Exchange of Notes concerning the Japanese economic cooperation for the execution of the Project for Research and Development of Mine Clearance Related Equipment to be executed by CMAC. The aim of the project is to test and evaluate the performance and suitability of demining machines and mine detectors manufactured by Japanese companies and research institutions. The Japan International Cooperation Systems (JICS) was selected as a consultant firm to supervise this important project. The total budget plan for the project is 416,000,000 yens.

Following the signature of the Exchange of Notes, a separate Memorandum of Understanding was signed between CMAC and JICS to lay out detailed project execution. A Selection Committee comprising of CMAC team, two officials from the Ministry of Foreign Affairs of Japan, two representatives from relevant institutes of Japan and a representative from UNMAS was formed to carry out the selection of test participants. The tasks of the Selection Committee included the review of the selection criteria and process, the assessment of the applicants' qualifications based on CMAC's Standard Operation Requirements (SOR), and the final selection of the participants.

There were five applicants in the solicitation process: Hitachi Swing Type, Hitachi Push Type, Kawasaki, Komatsu, and Shin Caterpillar Mitsubishi. Following the selection process, four of the applicants, namely Hitachi Swing and Push Types, Kawasaki and Komatsu, were accepted as the qualified participants for the tests in Cambodia. However, upon the arrival of the machines in Cambodia, Kawasaki requested to withdraw from the Project due to the technical difficulties they faced.

2. TEST PARTICIPANTS

With the withdrawal of Kawasaki machine, there were only three machines left: Hitachi Swing type, Hitachi Push type and Komatsu machines. Hitachi Swing type is a converted excavator-based type with a flail system attached to the arm. Hitachi Push Type machine is a converted excavator without arm and its flail attachment is fixed to its main body. Komatsu machine is a converted bulldozer with a tiller rotary attachment placed in front of the main body. The Komatsu machine can be operated by a remote control. All those demining machines are designed in such a way that could withstand from any kind of anti-personnel landmine blast.

In order to conduct this test successfully, CMAC assigned 36 deminers, 8 operators, 4 mechanics, 1 medic, 3 EOD members and other support staff such as management staff, drivers and security guards. In the execution of the project CMAC management team closely coordinated with JICS in both general management and technical aspects.

3. TEST PREPARATIONS AND TRAINING

There were three categories of tests: Performance, Survivability and Acceptance tests. Performance tests aim to understand the capabilities and efficiencies of the machines in terms of clearance productivity, clearance quality, mobility, fuel consumption and maintenance/repairs. The survivability tests were conducted to assess the safety of the operators inside the cabin and the machine durability against the anti-tank mine blasts. The Acceptance tests were conducted with the purpose to apply the performance of the machines in the real minefields in collaboration with CMAC's deminers.

Prior to commencing the test, all operators and mechanics assigned to each machine were trained by their respective manufacturers. The training lasted for two weeks upon arrival of the machines. The training was necessary to serve the purpose of the test as this test was fully conducted and evaluated by CMAC. After two weeks of the training the manufacturers were satisfied with the skills and performance of CMAC's operators. In addition to this training, CMAC also provided field training to its deminers on how to integrate with the systems. This training, both in machine operations and field integration, was an integral part of this test process as it ensured the safety, performance and integration were successfully carried out.

In order to achieve the mentioned tests, two locations were selected: one in Siem Reap for the performance and survivability tests and the other in Bavel District of Battambang Province for the acceptance tests. Three test conditions were applied in the performance tests: Dry, Light Bush and Wet conditions. There were ten lanes used for testing each machine: 4 lanes for dry condition, 4 for light bush, and 2 for wet condition. Each lane measured 10 m by 50 m. There were two types of anti-personnel mines used as targets: Chinese-made T-72A and Russian-made PMN2. Each lane had 9 PMN2 and 6 T-72A mines. The target mines were buried at the following depths: Lane 1 at 10 cm, Lane 2 at 15 cm, Lane 3 at 20 cm and Lane 4 mixed depths (10, 15, 20 cm). All mines were retrieved from the real minefields and were neutralized (booster removed) before being buried in the test lanes. However, they had the capability to detonate which could yield information whether they had been hit by the demining machines.

Survivability tests were also conducted in Siem Reap. For these tests, CMAC assumed the role of site preparations, deployment and detonation of targets and safety management. However, due to the limitation of resources, CMAC engaged MPC Research Co. Ltd. from Japan to jointly conduct the impact assessment through sensors installation and measurement of impact in terms of velocity and noise. To give a simulation of the real anti-tank mine impact, CMAC used one TM-46 anti-tank mine (6 kg of net explosive) with 1.5 kg of C4 (equivalent to 2.05 kg of TNT). The mines were placed at the centre underneath the attachment at 37 cm deep.

Acceptance tests were conducted in the real minefields in Bavel District of Battambang Province. Two minefields were selected for the tests. The site preparations, machine deployment and test procedures were all based on CMAC's demining SOP's in the real operations. As it was the first time such machines were deployed in the real minefields, CMAC faced a few challenges in terms of minefield selection, minefield preparations, and deployment of the machines and deminers in integration. The purpose of conducting the acceptance tests was also to measure the quality and efficiency of the machines in the real minefields, therefore CMAC deployed deminers to conduct 100% verification after the machines and strict records were maintained on fuel consumption and downtime due to maintenance/repairs.

4. MAINTENANCE/REPAIR

Maintenance and repair work were implemented by joint CMAC and manufacturers staff. Every morning, before the beginning of the test, maintenance work was executed and it took about half and hour. Repair was implemented after the machine found to be damaged from mine clearance. All the maintenance and repair were done on site. The tools to be used for the maintenance/repair, some were brought from CMAC workshop at Battambang and some were brought from Japan by manufacturers.

After the survivability test, damage was found on the attachment of demining machine swing type. Dust/fragment cover had been brown at great distant by the blast of 8 Kg of high explosive TNT. Some damages had been found at the attachment frame. By taking time and resource into consideration, manufacturer decided to replace it with new attachment. Hitachi push type machine, on the other hand, had undergone some chains/hammer/holder replacement. Likewise swing type machine, KOMATSU machine's tiller drum was damaged sever enough to be replaced with a new one.

5. TRANSPORTATION

With lack of CMAC transport vehicle big enough to move demining machine from port to the test field and via versa, Transido which is a private transportation company, had been hired to provide this services under close cooperation with CMAC. During transportation, transido took care of transport, safety and insurance while CMAC would conduct the offload and reload the machine to/from truck trailer or to/from ship at international Sihanouk ville port. Road assessment and route selection prior to transportation will be done by CMAC and transido.

The selection of the transport route is primary related to total gross weight of the machine (in combination with truck trailer) and the condition of road particularly the condition of the bridge. To open access road to the test site at Siem Reap, a poor, weak wooden bridge was dismantle and a new concrete bridge strong enough to support the gross weight of the demining machines was constructed. In other area, steel plates had been temporary laid on top of the existing pipe culvert to strengthen the structure and potholes had been refilled by earth/rock or leveled by CMAC bulldozer.

6. TEST RESULTS AND ANALYSIS

To enable the demining machine to experience as-close-as real minefield environment, CMAC used 450 Anti-Personnel landmines as targets deployed in dry, light bush and wet conditions (15 mines per lane). During the performance test, 377 landmines were destroyed either by detonating, by destroying its internal mechanism or by jamming mine mechanism. During the acceptance test at Battambang, additional 44 mines had been found and destroyed by joint demining machine and CMAC deminer attached to the machine. Remarkably, there were 2 mines had been destroyed by exploding on spot during the last day of swing clearance operation. This was a remarkable achievement and CMAC had well noted this outstanding result. Clearance productivity, on the other hand, the demining machines cleared 123,772 m^2. This excluding several thousands more square meters of minefield that CMAC demining team attached to the machine had cleared to open safe access road for the demining machine to be deployed both for training and for conducting the test.

6.1 CLEARANCE PRODUCTIVITY

Clearance productivity rate of push machine is remarkably fluctuated from more than 300m2 per hour to almost 700 m2 per hour. However, there is one good point about push type machine is that it's true cleared area is almost 100% which indicate that this machine could be able to clear almost all the location in the minefield. There is one point should be put into consideration is that the performance of this machine is changing between clearing low vegetation area and high vegetation. Its productivity rate is reduced by 34%.

No.	DESCRIPTION	MACHINE CAPABILITY
1	Average productivity rate at performance test:	567.45 M2/h
2	Maximum productivity rate (acceptance test):	697.67 m2/hour
3	Average productivity rate (acceptance test):	375.3 m2/hour
4	True cleared area:	95.26%
5	Un-cleared area or area for additional clearance:	4.74%
6	True productivity rate is reduced by	34%

6.2 MINE CLEARANCE QUALITY

Demining machine push type could break mine into pieces and its clearance quality is considered very high. According to the above figure, this machine strikes the ground and dispersed most object at average distant of 6.85m. The potential to break mine apart is limited.

No.	DESCRIPTION	MACHINE CAPABILITY
1	Average mine clearance quality:	87%
2	Fragment in operation area:	95 %
3	Fragment out of operation area:	5 %
4	Maximum distant of flying fragment:	6.85 m
5	Average broken mine:	1.6 pieces/mine

6.3 FUEL CONSUMPTION

Fuel consumption of demining machine push type is fluctuated around 38.2 liters/hour. Its fuel consumption rate doesn't change much when the machine changes the clearance condition between dry, wet and light bush condition. However, the productivity – fuel ratio is greatly changed.

No.	DESCRIPTION	MACHINE CAPABILITY
1	Average fuel consumption rate:	38.19 Liters/hour
2	Average fuel consumption rate (Performance test):	38.2 Liters/hour
3	Average fuel consumption rate (Acceptance test):	Fuel consumption is remain the same
4	Productivity - fuel ratio (performance test):	14.86 M2/L
5	Productivity – fuel ratio (acceptance test):	9.38 M2/liter
6	Productivity – fuel ratio is decreased by	37%

6.4 MAINTENANCE/REPAIR

Demining machine push type is in high demand for repair. For one hour repair, the machine could last only 1.13 working hour. If this machine works in the morning, it requires repair in the afternoon. It is apparent that this system requires repair almost everyday unless there is an upgrade of new version of flail system or the implementation of another new system that could last long in minefield condition.

No.	DESCRIPTION	MACHINE CAPABILITY
1	Average clearance duration:	2.9 hours/day
2	Maximum repair:	5 times/week
3	Maximum repair duration:	30 hours/week
4	Average repair duration:	4.5 hours/week
5	Average productivity/repair:	424 m2/repair hour
6	Average work/repair:	1.13 work hour/repair hour

6.5 SURVIVABILITY TEST RESULT

The measured data were compared with the FMV safety criteria, and the result showed that the machine tested was found to meet the safety criteria for the acceleration that relates to foot, ankle and spine injuries with a sufficient margin. Even though excess sound pressure over the safety limit was observed in the blast, but in overall there is no significant risk to the operator (base on MPC research Co., LTD report).

After the explosion, an examination was conducted to identify the impact of the blast to the attachment, to the main body, as well as to the cabin. The result showed that there was a minor damage to the flail system and it still operational. There were no damages to the body, to the cabin and to other supporting system such as hydraulic hoses, arms and other devices. Such minor damage could be easily repaired on site.

7. EVALUATION AND RECOMMENDATIONS

Hitachi Push Type machine is in itself a good design concept, which is a promising technology in mine clearance. There are a number of positive sides that shall be mentioned in here:

- Wide clearance span, enable the machine to achieve great quantity of clearance area in short period of time.
- It's hammer is strong enough to detonate landmine or destroy mine's internal mechanism
- The bottom of the machine is in V shape, which enables the machine to survive from large explosion underneath the machine.
- The cabin could be raised up and down, enable the driver to see the surrounding area clearly.
- Strong protection from any kind of flying fragment or pressure from the blast.
- Wide cabin screen enable the operator to have clear visibility
- A machine has a front metallic bar that it could push vegetation forward before it is struck by hammer

However, there are a number of points that should be addressed so that they could be used by the manufacturer for modification in order to maximize its performance and efficiency. Those points could be mention as follows:

- The current attachment with flail system required extensive repair, thus it should be modified from the flail system to the tiller system or preferably the rotary system. This system must be less repair work, equal or better performance to clear landmine, dig the ground deeper, throw the fragment, earth or debris in shorter distant and post-clearance pile of earth must be lower. If this system is not feasible for this machine, enhance the strength and capability of the current fail system so that it could minimize the repair work is highly recommended.
- Counter weight equipment shall be modified as follows:
    - Shall be made from several pieces where it can assemble or reassemble more easily.
    - Have the capability to lift high enough up to the point that it does not touch the ground during reload or download from truck tailor
    - Generate more productive use such as to level the earth behind the machine, remove fragments (using permanent or electric-generate magnetic field) and other useful things.
- If possible increase the width of the track so that the machine could be able to operate in soft ground
- When the machine got stuck in the mud, there shall have a mechanism that could push the machine upward high enough for the log or rock to be inserted beneath the track. This part is strongly recommended by CMAC deminer.
- Automatic re-oil system shall be equipped with the machine so that duration spend on daily maintenance is reduce and as a result it increases working duration.
- Equip front cover with metal frame to keep broke away chain, hammer and debris from flying to great distant.
- Clearance depth is important for mine clearance operation, therefore, push type machine shall equip with accurate depth detection equipment and this information shall be displayed to the operator.
- Push type's arm shall be able to move up and down, left and right at great angle. This arm shall be able to push the machine up high enough for log or rock to be inserted during recovery from getting stuck.
- High power fan shall be mounted on top of the machine to blow the dust away from the machine and increase the visibility of the operator particularly when it is operate in dry, dusty condition.
- Mirror shall placed at the right hand side of the machine so that operator could visually check the lane by themselves, as a result this machine could be deployed both direction (from left to right and from right to left)
- Because of the uncertainty of the present of AT mine in the ground and to provide safety to the operator, this machine shall be able to operate by remote control particularly in the suspected area (of having AT mine) at a distant of 1000m.

- Equip digital camera on the machine and live picture could be displayed at remote control box so that operator who use remote control could detect obstacle before directing the machine running into it.
- This machine shall built-in communication equipment (in helmet) so that operator and deminer could be able to communicate. If this system is not possible to provide such equipment, a plug shall be provided inside the cabin so that operator could recharge communication battery if it run out.
- Equip push type machine with more effective mechanism that could detonate AP mine if visibly found by the operator during mine clearance operation.
- Equip push type machine with mine counter equipment upon detonation during mine clearance operation.
- Equip the machine with mechanism (could be simple as sling shot) that could project the robe during recovery attempt from getting stuck in the minefield.

8. KEY ACHIEVEMENTS AND LESSONS LEARNT

8.1 KEY ACHIEVEMENTS

By executing this project, CMAC gained the following experiences and achievements:

- Through coordination between CMAC and JICS for Standard Operational Requirement was established in such a way that it was feasible to execute by the manufacturers and it meets the field requirements.
- The project was successfully completed on time, within budget and with safe environment both to machine and to man power.
- A good integration of the people and the machine provided a significant experience for CMAC
- Japanese manufacturers could get first-hand experience of the machine operating in the minefield that enables them to better understand their machine performance and efficiency so that improvement for future model is feasibly possible.
- CMAC could gain practical experience with mechanical demining machine in term of mine clearance operation, field management and coordination between the machine and the deminer and repair/ maintenance.
- Area cleared by the demining machine can be return to productive use
- CMAC R&D project planning, execution and management skill has been improved.
- Assets left behind by the project continue to benefit CMAC and the public long after the completion of the project.
- Key experienced institutions such as the International Test and Evaluation Program (ITEP), United Nation Mine Action Service (UNMAS) and Japanese Science and Technologies (JST) contributed to the process of this test and evaluation.

8.2 LESSONS LEARNT

Through the implementation of the project, there were a number of disadvantages and advantages that could be learnt. The following are some of the key issues which provide good lessons learnt for any future R&D project.

- Unpredictable climate changes should be taken into account during the project development
- The execution of the project under favorable conditions such as climate and terrain would minimize the negative impact therefore, any future project should be well planned with a wide range of considerations
- Infrastructure conditions related to the test locations should well assessed and planned in far advance
- While there were no major disruptions to the project, further improvement can be made in the areas of coordination with various ministries and authorities in order to ensure smooth implementation of the project.

- Human resource management and training under the project could be further improved to be well prepared for any unforeseen circumstances such as the withdrawal of participants from the project.
- The duration of the acceptance test was too short to obtain reliable information regarding machine performance and efficiency

9. CONCLUSION

Through thorough assessment of the data obtained from performance, survivability and acceptance tests a wide range of consultations and discussion among experts we can draw the conclusion that all the machines could not achieve clearance productivity rate of 500 m^2/hour for all terrains and condition. Their clearance productivity rate was fluctuating less than or over 500 m^2/hour depending on the terrains and soil conditions. Similarly, all those three demining machines achieved high mine clearance quality varied between 80% to 100% depending on terrains and soil conditions. In regard to the survivability, all the three machines sustained damages but could be put into operation again after a few days after some repair. The crews or the operators of the three machines survive from the blast without any physical injury.

To sum up, the three Japanese made demining machines are excellent demining tools that could eliminate the danger of mine threat and at the same time could turn the contaminated land into productive use at a promising achievement.

To gauze the extent of the maximum capability, effectiveness and efficiency of the machine after the modification, a further integration trial needs to be conducted in the real minefields in Cambodia with variety of ground condition, vegetation, long time deployment duration of the project, transportation of the machines under CMAC logistics, the burden of the maintenance/repair of the machines under CMAC mechanics with certain support from Japanese manufacturers and the handling of planning, execution, management and monitoring of the project by ordinary CMAC deminer.

In this respect, it is useful that CMAC request for a second phase of the project entailing a longer duration of integration trial of the machines in the real minefields in Cambodia. Such a trial will benefit CMAC, the manufacturers and the Japanese Government in a number of ways:

- It will provide more opportunity and time to learn more about the performance and quality of the machines in the real minefields.
- It will provide more understanding about the cost-effectiveness and efficiency of the machines under different terrains and conditions (dry, wet, light/heavy bush)
- It will prove the applications of the modifications made to the machines.
- It will give CMAC an opportunity to design and improve working SOP's applicable and practical for the operations of the demining machines.
- It will give CMAC a further learning opportunity to integrate the machines and manpower (deminers) in an effective and efficient way.
- It will give CMAC an opportunity to draw more experience in field management when operations of these machines are concerned.
- It will give an opportunity for the manufacturers to understand more about the performance and efficiency of their machines so they can improve them further to suit the field operations.
- It will produce actual clearance outputs which will result in safe land being returned to productive use by the local community. In other words, the next research and development project will be similar to a landmine clearance project.