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 RATE

Clearance productivity rate of swing machine is limited. This machine need to upgrade or modified in order to achieve the productivity rate of 500m^2/h. However, there is one good point about swing type machine is that it's true cleared area is almost 100% which indicate that this machine could be able to clear all the location in the minefield regardless of tree stump or other obstacle. There is one more point should be put into consideration is that the performance of this machine is changing between clearing low vegetation area and high vegetation. It's productivity rate is reduce by 15%.

No.	DESCRIPTION	MACHINE CAPABILITY
1	Average productivity rate at performance test:	357 m2/h
2	Maximum productivity rate:	424.48 m2/hour
3	Average productivity rate:	303.4 m2/hour
4	True cleared area:	99.97%
5	Un-cleared area or area for additional clearance:	0.03%
6	True productivity rate is reduced by	15%

6.2 MINE CLEARANCE QUALITY

Demining machine swing type could break mine into pieces and its mine clearance quality is considered high. According to the above figure, this machine strikes the ground and dispersed most object at great distant (around 20m forward). The potential to break mine apart is high.

No.	DESCRIPTION	MACHINE CAPABILITY
1	Average mine clearance quality:	89%
2	Fragment in operation area:	21 %
3	Fragment out of operation area:	79 %
4	Maximum distant of flying fragment:	23.55 m
5	Average broken mine:	2.8 pieces/mine

6.3 FUEL CONSUMPTION

Fuel consumption of demining machine swing type is fluctuated around 35 liters/hour. It would consume less fuel if the clear area has less vegetation and does not have tree stumps. However, the productivity – fuel ratio is greatly changed.

No.	DESCRIPTION	MACHINE CAPABILITY
1	Average fuel consumption rate:	34.54 liters/hour
2	Average fuel consumption rate (Performance test):	36.1 liters/hour
3	Average fuel consumption rate (Acceptant test):	4%
4	Productivity - fuel ratio (performance test):	10.34 m2/l
5	Productivity – fuel ratio (acceptant test):	8 m2/liter
6	Productivity – fuel ratio is decreased by	33%

6.4 MAINTENANCE/REPAIR

According to the above table, demining machine swing type requires about 17 repair hours to clear one hectare of minefield. Each day it could clear only one morning and requires the whole afternoon for maintenance.

No.	DESCRIPTION	MACHINE CAPABILITY
1	Average clearance duration:	3.8 hours/day
2	Maximum repair:	3 times/week
3	Maximum repair duration:	17 hours/week
4	Average repair duration:	3.7 hours/week
5	Average productivity/repair:	633 m2/repair hour
6	Average work/repair:	2.09 work hour /repair hour

6.5 SURVIVABILITY TEST

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 medium damage to the attachment and flail system. There were no damages to the body, to the cabin and to other supporting system such as hydraulic hoses, arms and other devices. Such medium damage could be repaired on site with considerable cost and effort.

7. EVALUATION AND RECOMMENDATIONS

Hitachi Swing Type machine is in principle a good design for mine clearance operations and community development. This machine performed reasonably well and made a remarkable achievement in all test areas. In general, the machine has a number of strengths:

- The cabin was designed with a good safety standard.
- With the advantage of the extended arm, the safety of the operator inside the cabin is greatly enhanced.
- The operational deployment is optimized in the real minefields as the Swing attachment can reach virtually every part of the minefields during operations.
- Operator has good visibility from the cabin.
- Self recovery capability with its own arm provides a great advantage in remote areas.
- The multi-function attachment provides a great advantage to clear obstacles in the minefields such as removing tree stumps, detonating anti-personnel mines, and leveling small hills.
- The machine can be used in development activities such as digging ponds and canals and leveling roads.

However, we have identified a number of areas for improvement that could enhance this demining system to achieve better performance and meet the field requirements. The following areas are recommended to be improved or modified:

- The total gross weight of the machine is a major issue in Cambodia. The total gross weight should be reduced to less than 30 tons. This enables the machine, within appropriate distant, to have more freedom of movement across poor infrastructure in Cambodia rural without having to dismantle and reassemble. Thus, in turn, enable CMAC to safe time, money and resource that could be used for other useful activities.
- The current attachment with flail system required extensive repair, thus it should be modified as follows:
    - 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.
    - The new attachment is best to have multi-functions beside mine clearance: pushing the tree down, grabbing and holding object and removing obstacle. This attachment must be stronger than the current attachment.
    - Should be lighter to enable the machine to extend the arm to the maximum without destabilizing the balance of the machine
- The counter balance should be built in small pieces of around 1 ton each.
- 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.
- Provide a space where operator could keep demining equipment tool such as metal detector to detect suspected object such as landmine, UXO or AT
- Equip swing type machine with more effective mechanism that could detonate AP mine if visibly found by the operator during mine clearance operation.
- Equip swing type machine with mine counter equipment upon detonation
- 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.