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COUNTERMINE VEHICLE STUDY: PROGRESS REPORT

by

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OTTAWA, CANADA

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OTTAWA, ONTARIO

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ABSTRACT

This report documents the progress to date on the Countermine Vehicle Operational Research study. It addresses the project aims and objectives, the study methodology, the study assumptions, the analysis plan, the measures of effectiveness, the data and information sources, the scenarios, and simulation development.

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PROGRESS REPORT

I. INTRODUCTION

AIM

1. The aim of this report is to document the progress to date on the Countermine Vehicle Operational Research (OR) study. This report addresses the project aims and objectives, the study methodology, the study assumptions, the analysis plan, the measures of effectiveness (MOEs), the data and information sources, the scenarios, and simulation development.

THE COUNTERMINE OR STUDY

2. The Countermine Vehicle OR study is sponsored by Chief Research and Development (CRAD). It is to provide a comparative analysis of manned and unmanned vehicles in the countermine role. The study takes advantage of the unique Canadian situation in which manned and unmanned detection systems are being built using the same detectors. Hard experimental data will be available, and will be used in the study. The experimental data will be extracted from the following projects:

a. Project L2684 Improved Landmine Detection Capability (ie the manned countermine vehicle which is being constructed, under contract, for Director Military Engineering (D Mil E)); and

b. Project D6300 Improved Landmine Detection (ILD) System, the robotic vehicular landmine detection system which is under development at Defence Research Establishment Suffield (DRES).

3. The comparison is to be completed in terms of survivability, ability to complete the mission, and time to complete the mission, in a carefully selected set of scenarios. It is to provide insights into the use of robotics in a countermine role. Survivability is to take into account the survivability of the personnel manning the system, as well as of the system itself.

4. The results of the study, supplemented by experimentally validated results, are to be used to guide the development of future CRAD countermine projects, and to provide guidance to D Mil E in terms of robotics. Study results are also to be shared with The Technical Cooperation Program/Technical Liaison Group 5 (TTCP/TLG5) members. It should be stressed that this is a systems, and not a configuration, study.

RESOURCES

5. A three person team was assembled to complete the study. The team members belonged to CRAD, D Mil E, and Operational Research Division (ORD) respectively. Each team member contributed unique knowledge, skills and expertise to the study. Valuable technical support for the study was also provided by DRES personnel.

6. The team held a series of meetings in order to flesh out the project aims and objectives, identify data and information sources, develop the study methodology, identify the study assumptions, agree on the MOEs and the analysis plan, develop the scenarios to be considered within the study, and develop the simulation tool.

7. During a visit to DRES interviews with key developers were conducted, and a first-hand look was taken at the technology being used for the robotic prototype. Information and reference material on the robotic system were gathered during the DRES visit and by use of the ORD library. Information on the manned system, and on methods of employment and tactical use for both systems, was obtained from D Mil E 4-5.

II. STUDY PARAMETERS

THE SYSTEMS BEING COMPARED

8. The manned system consists of a single vehicle that consists of a protection package and a detection package. The tele-operated robotic countermine system consists of the robotic (unmanned) lead vehicle, the trailer, and the manned command and control vehicle. The simulation to be used by the study models the single manned component and the three robotic system components.

9. Each system is to be used to sequentially detect, locate, and mark mines. Systems are not to be used to classify or identify targets. They are not to be used to destroy or neutralize mines. The mines are rendered safe at a later time, by a follow-on team. For both systems, the data fusion and decision making is made via "man in the loop".

SENSORS

10. The two systems are fitted with the same sensors, namely: an electromagnetic induction (EMI) detector, an infrared (IR) imager, ground probing radar (GPR), and a thermal neutron activation (TNA) detector. The robotic system is also equipped with a visual camera. EMI, IR, and GPR are scanning technologies that detect properties associated with mines while the vehicle moves. The IR scans forward, whereas the EMI and GPR scan down. The TNA is used as a confirmation technology only. It operates with the vehicle stationary over a suspected target, and can confirm the presence of explosives.

11. EMI consists of exposing a conductive object to a time-varying magnetic field and detecting the secondary magnetic field produced by eddy currents induced in the object. Buried ordinance and mines having metallic casings or components may be amenable to detection by this method. Since EMI detects only metal, it is useless for the detection of purely nonmetallic mines. The metal content of the soil (eg battlefield debris) affects the false alarm rate that can be expected through use of EMI.

12. Thermal IR detection or IR radiometry relies on measuring the spectrum or intensity of IR radiation emanating from a material. If a mine is buried in a medium such as soil, the normal heat flow pattern in the soil will be altered if the thermal properties of the object and the disturbed medium around it are sufficiently different from the undisturbed medium. This will cause a change in the temperature profile above the surface of the medium directly above the occlusion. IR detection rates vary, and are a function of soil type and compaction, moisture, shadow, time of day, diurnal thermal cycling, and temperature and precipitation history.

13. GPR sends electro-magnetic signals into the ground and analyses the backscatter wave. GPR does not perform well if there is strong and variable soil clutter, low target contrast, or nuisance targets such as rocks and soil inhomogeneities.

14. The TNA detector can detect high concentrations of nitrogen typically found in high explosives. In TNA, a neutron from a radioactive source or electronic neutron generator excites a nitrogen-14 nucleus and causes it to emit characteristic gamma rays. The neutrons penetrate the ground, interact with buried objects, and result in gamma ray signals which outline the elements which make up the buried objects.

15. Each sensor has its strengths and limitations. The aim of employing a suite of sensors rather than one single sensor, and of using data fusion, is to reduce the false alarm rate and increase probability of detection. This approach brings with it increased system cost and complexity. For a more detailed description of these sensors, please refer to Ref 1.

PROTECTION

16. The manned system is mine hardened and blast resistant. It is equipped with a Pearson segmented V blade and with a magnetic signature duplicator (MSD). The robotic vehicle, on the other hand, is a developmental system and has no means of protection other than its light weight. The latter is a passive form of protection against AT mines. It was designed with the assumptions that (Ref 2):

a. there would be a protection vehicle which precedes it and which would remove anti-personnel (AP) mines and precondition the road (it should be noted that a protection vehicle does not exist at this time);

b. its ground pressure signature is insufficient to activate antitank (AT) mines (this is a design limitation); and

c. its electromagnetic signature is insufficient to activate antitank (AT) mines (this has yet to be experimentally validated).

CONFIGURATION AND DATA FUSION

17. The two systems are configured differently, and hence have different data fusion algorithms. At the time of writing of this report, the configuration of each system (ie the physical layout of the components), the method of operation of each system, and the choice of data fusion strategy were not yet fully specified. Testing on the robotic prototype is

scheduled for June 1997. The manned prototype is scheduled for completion in fiscal year 1998/1999.

MEASURES OF EFFECTIVENESS

18. The following measures of effectiveness (MOEs), relating to system survivability, to the system's ability to complete the mission, and to the time taken to complete the mission, are to be addressed by the study:

a. **Survivability MOES**

(1) over all the runs conducted for a scenario (or scenario component), the fraction of all the runs in which the system completed the mission,

(2) over all the runs conducted for a scenario (or scenario component), the average number of times that the system suffers repairable damage during the mission,

(3) over all the runs conducted for a scenario (or scenario component), the average number of persons injured or killed during the mission (consider only personnel who are manning the systems under consideration eg do not consider injury or death of personnel who neutralize the mines),

b. **Ability to Complete the Mission MOEs**

(1) over all the runs conducted for a scenario (or scenario component), for each AT and each AP mine type along the route being cleared, the fraction and number of such mine types that are detected,

(2) over all the runs conducted for a scenario (or scenario component), for each AT and each AP mine type along the route being cleared, the fraction and number of such mine types that are missed (ie not detected; it is this factor that drives the need for protection),

(3) over all the runs conducted for a scenario (or scenario component), for each AT and each AP mine type along the route being cleared, the fraction and number of such mine types that are detonated,

(4) over all the runs conducted for a scenario (or scenario component), the average number of false alarms generated by the system,

c. **Time to Complete the Mission MOEs**

(1) over all the runs conducted for a scenario (or scenario component), the average time required by the system to complete its mission or suffer a kill (during the analysis stage, depending on study results, it may be desirable to look at average times for mission termination separately for the cases in which the mission was completed and for the cases in which the system was unable to complete the mission; note that as this is a relative comparison of the systems, it is not the absolute value of these times that is significant, but rather only the differences in the mission termination times for the systems under consideration), and

(2) over all the runs conducted for a scenario (or scenario component), the average time required to complete the neutralizing aspect of the mission (this provides an indication of what the false alarm rate costs in terms of time; as above, note again that as this is a relative comparison of the systems, it is not the absolute value of these times that is significant, but rather only the differences in the times for the systems under consideration).

19. Values for the above MOEs are to be produced for each scenario, and for each scenario component. Note that scenarios can be broken down into components, each component corresponding to a unique set of conditions under which the operation must take place (eg each component may relate to a different route/soil type). Conducting runs for each scenario component, as well as for the whole scenario, allows the examination of how well the system performs for the mission overall as well as how well it does in each of the conditions associated with each scenario component.

20. As the simulation is further developed, the above list of MOEs may need to be modified or added to. In addition, during the analysis phase, it may be desirable to add new MOEs. For example, depending on how close values for individual runs lie to the average value over all runs, it may be interesting to also look at the minimum and maximum values for certain MOEs.

COSTS

21. It was decided that the relative costs of the systems under consideration would not be addressed by the study. The decision was based on the substantial amount of time and effort needed to gather the data to estimate these costs. Also, manpower savings would not be considered within the context of the study.

III. METHODOLOGY

22. As stated above, the aim of the project is to provide a comparison of robotic and manned systems in terms of survivability, ability to complete the mission, and time to complete the mission in a select set of scenarios.

23. In addition to comparing manned and unmanned systems, a comparison with a base line case should be made. The base line consists of how operations are currently conducted, without the use of either system. It relies on the use of hand-held prodders and metal detectors, and on the subsequent clearance of each mine by hand. This comparison is an issue of personnel survival and speed. It should be noted that in mine clearing, as opposed to mine breaching, the need for safety and quality overrides the need for speed. The comparison to the baseline would show the differences in performance level that result from the introduction of the sensor suite and data fusion algorithms described above.

24. The study is to provide a comparative analysis of the systems. That is, the analysis is to show how well the systems perform relative to each other and to the baseline, and will not predict in absolute terms how well each system performs.

THREATS

25. The following threats are to be modelled: surface laid and buried AP (pressure activated, trip wire) mines, surface laid and buried AT (pressure activated, tilt rod, magnetic influence (MI)) mines, direct fire, indirect fire, and obstacles (ie culvert, abatis, crater, checkpoint). The study will consider metallic and nonmetallic mines. Off route mines, area defence mines, and control activated mines will not be modelled. The unexploded ordinance (UXO) threat will not be modelled as the procedure for dealing with UXO is more or less the same for both systems (and similar to that used for detected AT mines, which are modelled), the time to deal with UXO is also more or less the same for both systems, and the probability of a kill by UXO is negligible. The direct and indirect fire will be modelled as effective fire (ie enemy is shooting with an intent to kill, not just to harass). The types of fire to be modelled are 5.56 rifle, 7.62 sniper, mortar, and 155 howitzer. This choice is based on significant incident reports collected by Director Land Requirements (DLR). The modelling of the obstacles will take into account the reconnaissance phase during which personnel dismount from their vehicle and assess the situation on foot.

26. In particular, the following mine types are to be considered within the scenarios to be modelled: TMA-3 (pressure activated, AT), TMA-5A (pressure activated, AT), FFV 028 (MI, AT), TMRP-6 (pressure activated, MI, tilt rod, AT), HPD F2 (MI, AT), Valsella 69 (pressure activated, AP), PMN (pressure activated, AP), 72A (pressure activated, AP), M18A1 (known as the Claymore) (tripwire, AP), POMZ-2 (tripwire, AP), and ADAM (scatterable mine).

THE SIMULATION

27. The team conducted a search for existing simulations, models, and other OR tools which could be used as is, or with limited modifications, for the study. Although there were models which dealt with certain parts of the problem being addressed (eg the Minefield Effectiveness Simulation Model (MESIM) could have, with slight modifications, been used to deal with the AT component of the study), there was no tool which addressed the whole problem being studied. It was decided that the most efficient way to proceed was to build a simulation from scratch.

28. The team decided to use a Monte Carlo approach (ie to build a simulation which uses random numbers to generate results, and hence is not deterministic). The simulation is to be run a number of times for each scenario (or each unique component of each scenario), and values for the agreed upon MOEs produced. The number of runs to be conducted for each scenario are to be determined during the early analysis stage, using statistical techniques.

29. The simulation is to model all the threats discussed above, as well as the tasks and missions performed by the contending systems and by the personnel manning those systems, under various operational scenarios (eg detection and marking of mines, reconnaissance of obstacles, false alarms, time to repair systems (if possible to repair) after they suffer a hit and the corresponding performance degradation (if any), etc.).

30. Logistics, although an important criteria in the evaluation of the systems, will not be considered within the context of the study. Depending on the availability of mean time between failure data, the simulation will model the breakdown of equipment due to factors other than mine detonation. The breakdown will be taken into account in terms of ability and time to complete the mission. The process of neutralizing the mines after they had been detected will be modelled only to the extent of considering the time required to complete this task (eg possible injuries resulting during this phase of the mission will not be considered).

31. The simulation is to model the actual system configurations and modes of employment for the systems from which experimental data will be gathered, as they are known or are expected to be, at the time of the study. It should be noted that some judgement will be involved in identifying the latter, as it will not be known completely until both systems have undergone testing.

32. The disruption of robotic optics (eg due to vulnerability to dust, ice, etc.) may be modelled, depending on data availability. The data link and data rate, as well as the time for the operator to interpret the IR imagery, will be modelled indirectly through the choice of detector system speed. For the tele-operated system, the likelihood of failure in the data link will not be modelled. Operator fatigue and operator training, and how this affects overall system performance may be modelled, depending on data availability. The resolution of the optics is assumed to be a first order effect in terms of overall system performance. It will be modelled indirectly by taking it into account when determining the system's probability of detection of a mine or declaration of a false alarm. Data fusion, signal processing, and data

transfer are key elements governing the speed, performance, and effectiveness of the systems. They will be modelled through data inputs for probability of detection and clearance speed. Note that neither system will operate at convoy speeds.

33. The simulation is to concentrate only on those aspects in which there would be relative differences between the systems, and is to provide values for the MOEs listed above. That is, the simulation is to concentrate on differences between the systems in terms of survivability , ability to complete the mission, and time to complete the mission. Note that at the time of writing of the report, the simulation design is only partially completed.

DATA SOURCES

34. The study results will only be as good as the input data on which the study is based. The study will make extensive use of experimentally generated data whenever possible. It will use data generated by expert opinion and judgement only when experimental data is unavailable or too costly to obtain. The study will not consider notional systems. It will look solely at systems which are developmental, under construction, or currently in use. As such, the study is unique. It's focus is different from some earlier work on robotic systems (Ref 3) which is based on notional systems and wholly on expert judgements and opinions.

35. The data for the robotic system is to come from DRES testing on the prototype, and possibly through additional experiments performed by DRES in support of the OR study (eg to determine the probability of damage to system subcomponents, for example through the transmission of shock and vibration into the sensitive electronic assemblies). Liaison with DRES has been initiated to ensure that the OR study data requirements are understood and will be met whenever it is possible and feasible to do so during testing and experimentation. The data for the manned system will have to come from subject area experts, as the OR analysis is scheduled to take place before completion of the construction and testing of the manned vehicle. Experts may choose to give a single value or a range of values in which they think a certain data parameter will fall. In cases in which a range is provided, sensitivity analyses will be conducted to determine how choosing the minimum, average, and maximum values within that range affects the overall MOE values.

THE SCENARIO

36. The study results will be highly scenario and mission dependent. Different scenarios, conditions (eg weather, day or night operations, metal content of soil/metal debris, etc.), threats, and tasks could lead to very different results and conclusions. The study sponsor has been assigned the responsibility of choosing scenarios for use in the study.

37. The scenarios chosen cover a wide range of conditions under which the systems are expected to operate. The scenarios will, once they are completely specified, incorporate all the critical factors which affect system performance. This will allow the study to provide an indication of the quality of performance which could be expected in various situations (eg rain, snow, soil type, presence of nuisance targets such as rocks, etc.). Scenarios will be limited to roads and routes in which neither system will have difficulties in terms of mobility or ability to handle the terrain.

38. The threats to be modelled have already been discussed. Note that the threats are not meant to be a reflection of any specific nation's forces or equipment. Rather, they are representational threats chosen by D Mil E experts to best assess projected mine and countermine capabilities of the systems under consideration in the peacekeeping and peacemaking scenarios in which they are most likely to be employed within the next ten years. They are the mines typically used in situations such as those encountered in Somalia and Yugoslavia. They do not represent the most expensive, most technologically advanced mines on the market today or within the next ten years.

39. A set of nine scenarios, and variations thereof (eg in weather, etc.), are to be considered within the study, and are outlined below. The nine scenarios are all route/road clearing operations during a peacekeeping/peacemaking mission. They include:

a. establishing and expanding a port of entry;

b. establishing and expanding lines of communications; and

c. establishing and maintaining forward areas;

in high, medium and low threat level situations.

40. The scenarios incorporate differences in infrastructure, road, terrain, and climate. The "establishing and expanding a port of entry" scenario consists of 50 km of rolling plain, including 25 km metalled roads, 15 km dry tracks, 10 km saturated tracks, 40 culverts, 1 town, and 4 villages. The "establishing and expanding lines of communications" scenario consists of 50 km of desert/bush, including 20 km tracks, 20 km sand/gravel, and 10 km bush. The "establishing and maintaining forward areas " scenario consists of 50 km of hills/mountainous tracks, including 25 km with slopes greater than 30 degrees, 10 km with frozen ground, 50 culverts, 2 towns and 4 villages. For each scenario, the route is assumed to be 4m wide (this is the maximum width the sensors can examine on a single sweep) and the speed while clearing is assumed to be 5 km/hour (unless data available at a later date indicated otherwise). These choices are based, in part, on Ref 4.

41. The high, medium, and low threat levels can be described in the following manner:

a. High Threat (Red) - In this situation, you know that landmines have been deployed. The mining could have been a result of a recent battle, a result of your being targeted, or known to you through local intelligence. Usually, mines have been put in fast and are either laid on the surface of the route or are buried very close to the surface, and little or no effort has been made to camouflage them. This situation, in comparison to the medium and low threat situations, is characterized as the situation in which the largest number of mines are laid along the route/road being cleared.

b. Medium Threat (Yellow) - In this situation, there has been enemy activity, but it is not necessarily directed at you. The mining could, for example, be on a route you travel and had cleared earlier. Usually, mines have been laid at leisure and are less easy to detect than those in the high threat situation (eg may be dug deeper, may be well camouflaged). This situation may be characterized by a small number of mines and large roads.

c. Low Threat (Green) - In this situation there is very little risk of encountering a mine. An example would be maintenance of a main service route (MSR) which is travelled by us and by the combatants (the latter is a good indicator that the combatants have not put mines in).

42. The procedure for dealing with "sensor hits" depends on the number of sensors involved in the "hit", on the threat level, on the configuration of the system (eg will the vehicle be past the detection once it sounds the alarm), and on operator experience and judgement. In high threat situations, all likely mine sites as identified by "sensor hits" are likely to be investigated by the follow on team responsible for neutralizing the mines. In low threat situations, the operator may decide to bypass certain "sensor hits" without marking them because, based on operator experience and judgement, these sites are highly likely to be false alarms. The procedures for dealing with "sensor hits", and how they affect time to complete the mission, are modelled by the simulation.

43. The number and specific mix of mine targets in each scenario depends on the threat level. It has yet to be decided upon. However, the starting point for this decision will be based, in part, on Ref 4. The likely mine targets to be chosen for the medium threat level scenario are: 2 AT mines (both buried, 1 pressure, 1 influence), 5 AP mines (3 on the surface, 2 buried), and 5 scatterable mines (on the surface). Other scenario characteristics (eg number of obstacles, direct and indirect fire, characterization of critical parameters (eg soil type, moisture, presence of nuisance targets such as rocks)) affecting system performance are yet to be specified.

COUNTERMINE STUDY ASSUMPTIONS AND LIMITATIONS

44. As noted above, the results and conclusions of the study will be highly scenario, mission, and threat dependent. The validity of the results will depend on the quality of the input data used in the simulation. The study will provide a comparative analysis of the systems. That is, the analysis is to show how well the systems perform relative to each other and to the baseline, and will not predict in absolute terms how well each system performs or the absolute time required to complete a mission. Other assumptions and limitations will be noted as the simulation design nears completion.

IV. CONCLUDING REMARKS

45. The aim of the study is to provide a comparative analysis of manned and unmanned vehicles in a countermine role. The study is to be a systems, and not a configuration, study.

46. The team discussed the significant differences in the concept of operations and the protection levels of the two systems from which the data for the study will be drawn. The team also discussed whether a useful systems comparison of manned and unmanned vehicles could be made based on the data available from these particular two systems, and without the introduction of a notional protection device or protection vehicle for the robotic system (note the discussion above on protection and the assumptions set out in Ref 2). The team was reluctant to have the study lose its hard connection to experimental data, and noted that one of the study constraints is that the use of notional systems and devices is to be avoided.

47. The sponsor, after being briefed on the progress to date on the study and being requested for guidance for the way ahead for the project, directed the team to document the work completed to date and to put the study on hold pending the further development of the robotic vehicle to include AP landmine protection. As such, this report has been written. The work conducted to date is useful in that it can form the basis for a future OR study, should the sponsor decide to re-open the study at a later date.

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