FUTURE TECHNOLOGY-CONCEPT EXPLORATION & WEAPON AUTONOMY

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***Abstract* — The need for innovation and technology insertion within warfighting is greater than ever; however, the impact of technology too often drops short of expectations due to limited utilization or operational failure. This paper discusses a programme that aims to improve technology insertion through the application of collaborative operations analysis in Future Technology-Concept Exploration (FTCE). An incremental-spiral analysis methodology is being developed and applied to understand the impact, effectiveness and utility of technologies and their associated concepts of employment. The paper will discuss the concepts behind FTCE, the incremental-spiral analysis methodology, and the first programme activity focused on autonomous weapons exploration.**

Keywords— operations analysis, OA, systems analysis, experimentation, future technology, autonomy, collaborative weapons, spiral development, technology exploration.

I. INTRODUCTION

To fight and win in the operations of the future the Australian Defence Force must be able to keep pace with technological changes and seize the opportunities presented by these changes. Scientists and engineers focus technology development on improving technical performance, however such improvements do not always provide military impact. Military personnel extend and create Defence concepts without complete knowledge of the limitations and capabilities of new technologies, or their ability to integrate into broader systems. The understanding of where and why technologies work (and fail), and the battlefield effects they produce are not commonly utilised in current technology development processes [1], [2].

Innovation programs generate new technologies and pursue transformation via the use of agile and iterative processes common in software and systems engineering [3]. This agile method is unfortunately not standard practice for Government and Defence [4], where meeting military needs public justification are paramount. Similarly Operations Analysis (OA) does not commonly employ agile or spiral methods; rather utilising "hard" methods on known data or judgement-based OA where information is incompletely understood [5].

This situation raises two questions:

How can Army capitalise on innovation, exploit technological advances, and shape upgrades to ensure the achievement of definitive battlefield impact?

Where should Defence be placing its precious time and money across a broad and ever-changing technology space?

Defence needs to be more agile and effective in this modern world [6]. A more cohesive, focussed and collaborative methodology is needed to achieve technology and concept development in synergy – driving military innovation by connecting analysts, users and developers.

Systems Analysis (SA) and OA approaches can be used to explore technologies and their associated concepts of use within appropriate contexts to understand and evaluate their impact in the land operational environment. Land Capability Analysis (LCA) in the Joint and Operations Analysis Division is therefore developing a new programme entitled Future Technology-Concept Exploration (FTCE) to ensure greatest use of new technologies to maintain Army's competitive advantage and robustness in all operational futures.

II. FUTURE TECHNOLOGY-CONCEPT EXPLORATION

The FTCE programme will provide a military effectiveness context to aid technology insertion and development support to the Land Domain. It will support Defence Science & Technology (DST) Group and Industry technology development, aid Army in its increasing focus on innovation and future technology (aligning with Army Innovation Day) and assist current Army programs and futures in technology decision-making.

A. What is FTCE?

The FTCE programme aims to understand the impact, effectiveness and utility of incoming technologies and thereby identify the best Return on Investment for Army and Defence in new technologies through the use of OA and SA. The use of "Technology-Concept" reinforces co-evolution of technologies with their concept of employment.

This analysis will concentrate primarily on exploration with some elements of evaluation and will seek to identify impacts at the Combat Team and above levels. Studies will focus around the Integrated Investment Plan (IIP) timeframe to support of the realisation of the IIP and achievement of Army's force design objectives. The implication of this timing is that technologies of interest must be able to be fully realised and fielded in 5-10 years or with Technology, System and/or Concept Readiness Levels (TRL-SRL-CRL) of 3-7.

FTCE studies can be categorised based on the readiness level of the technology and/or concept. Consider, as an example, a relatively new technology (low TRL) utilised in

current warfighting operations. Some insights that could be generated by such studies could include:

- Identifying the most useful technology aspects in terms of operational effectiveness;
- Identification of the technology changes most suited to operations;
- Discovery of fundamental inputs to capability (FIC) interactions and impacts; and
- Understanding the impacts of small changes to the use of the technology (e.g. at doctrine/tactic level) that may impact the operational effectiveness.

An essential component to these studies is ensuring appropriate prioritisation, direction and selection of studies via engagement with key stakeholders – Army and technology developers within DST, Industry and Academia. Conducting an initial analytical triage on the incoming science & technology (S&T) requests will be required to determine the type of problem, S&T solution options, priority and resources necessary. After this initial triage and studies have been shortlisted, stakeholders will be engaged to make final selections into FTCE programme and campaign plans.

B. FTCE Engagement Philosophy

FTCE investigations require high degrees of engagement and partnership to ensure success. This includes partnership with Army to generate and prioritise the technologies and associated concepts under investigation. Understanding the technical limitations and opportunities provided by technologies is vital to ensure the credibility of studies. This necessitates collaboration with Industry and/or DST technology development teams. Technology analysis should also support and collaborate with other technology and innovation activities within and external to Defence.

Initial alignment and involvement with Army Innovation Day is desired to deliver quick wins, however a more cohesive model will need to be identified to understand the needs of all stakeholders: Army project/program managers, future concept developers, and force designers.

C. FTCE Methodology

FTCE is not about making the technology work, but understanding the so what, how, where and when it worked. Therefore, FTCE studies are fundamentally multi-disciplinary and multi-method to ensure breadth of coverage. They require iterative exploration and insights generation to refine technology application and operational utility, followed by systems and sensitivity analyses to identify gaps, opportunities, cost-benefit and trade-off understanding. Analysis should assist both the technology developer and user in decision making, so timeliness, flexibility, re-use, context and proven methods are important. That is the use of a spiral and incremental style of OA that pairs exploration and evaluation.

Evaluation concerns the judgement or calculation of the quality, importance, amount, or value of something [6], while exploration is about searching and discovery [6]. The FTCE programme requires significant elements of discovery to identify the operational applications of the technology system under investigation. Effectiveness and impact require evaluation and typically utilise significant amounts of data based on well understood elements. However, with new technology there is significant uncertainty and definitive data is often unavailable. Impact and effectiveness assessments are conducted in an experimental mode, identifying insights and speculative results that then direct the next phase of investigation. These experimental insights provide greater understanding of the limitations and opportunities presented and the FIC changes required to impact mission outcomes.

D. The FTCE Autonomy Campaign

A campaign approach to the FTCE programme was developed to deliver outcomes aligned to the methodology described above. Four primary output streams were identified:

- Spiral OA Campaign exploring technology-concepts;
- Technology exploration for specific DST technology development;
- Army Innovation Day assessment and evaluation support; and
- Incremental Spiral OA methodology and toolbox development.

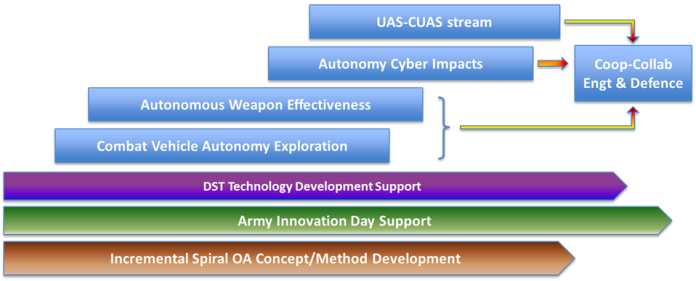

Fig. 1: The FTCE Programme

The initial campaign is focused on 5 study areas in the area of autonomy. Each of the areas cross-support each other linking a series of related technology-concepts toward the long-term goal of understanding autonomy within collaborative engagement and defence. The campaign topics (below) were chosen based on impending Australian Defence project/program needs and technology development / innovation programs currently underway.

1. Vehicle Autonomy in Combat;
2. Autonomous Weapon Exploration;
3. Cyber Impacts in Autonomy;
4. Unmanned Aerial Systems (UAS) & Counter UAS; and
5. Cooperative & Collaborative Engagement & Defence.

III. Spiral Operations Analysis

FTCE is based on an incremental-spiral form of OA and SA to support technology development and technology insertion decisions and their associated concept development. The development of this incremental-spiral OA technique will be a core component of the research required within the FTCE programme. The methodology is being built on, and aligned with, the systems and software engineering paradigms of agile,

lean and spiral development [3] used commonly in modern technology and innovation development.

A. *Aims*

The aim of incremental-spiral analysis is to build the understanding of technology application and effectiveness in conjunction with technology innovation builds. Analytical results must be sufficient to provide insights or answers to progress the development and use of technology to the next level. Identification of the appropriate OA-SA methods to support this will be a key component of the research.

B. *Methodology*

Incremental-spiral analysis examines the broad systems issues and clarifies assumptions to identify potential impacts, detect sensitivities to assumptions, and generate deeper analyses to confirm the impacts, assumptions and overall effectiveness. That is, combine and utilise numerous standard quantitative and qualitative OA-SA techniques to "explore".

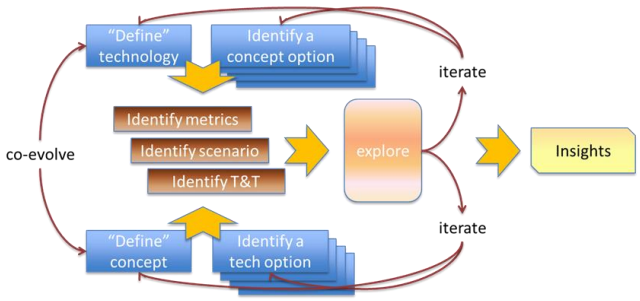

Fig. 2. The Spiral Analysis Methodology

The incremental-spiral analysis methodology is a multi-method approach necessitating the exploration and analysis of key technology application break points through multiple study loops. A single loop may define the technology system and explore the impacts of various concepts of employment. In a secondary loop, changes in the technology system may be explored through fixing certain aspects of employment. Such iterations of exploration may occur across analytical studies or even within a single study, permitting aspects of the technology and concept of employment to co-evolve (see Fig. 2).

Incremental-spiral analysis requires the analyst to step through the technology solution and operation space to deepen comprehension of the utility of the technology system of interest. Each spiral or step of analysis includes a touch point with technology developers to inject effectiveness knowledge gained, confirm technology changes and re-adjust analysis needs prior to the next element of the spiral. Fundamental aspects of incremental-spiral analysis are shown in Fig. 3 and described here:

1. OA-SA is conducted in cycles or "spirals" with knowledge extended in each investigation;
2. Knowledge and risk are assessed after each spiral to determine next steps;
3. The first loop is usually a quick (almost back-of-the-envelope) analysis to identify key aspects of the technology, analytical questions and opportunities;
4. At the end of each investigation (Q1), questions are asked: What did we learn? Do we need to know more? Where to next?;
5. If further exploration is not needed or information is required from others (military or technical), then a different spiral investigation can begin on a new topic area (Q2);
6. Otherwise the knowledge gained may drive the need to go deeper / into more detail (Q1b), go further into the same area and question (Q1a), or go laterally onto a different question within the same area (Q1d); and
7. Another analysis cycle is then conducted extending knowledge (and return to item 4).

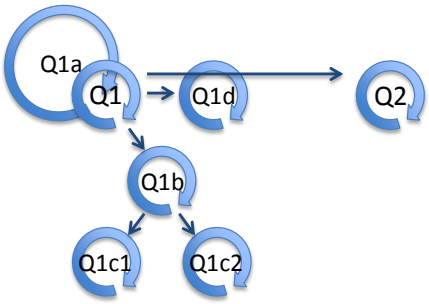

Fig. 3. Spiral study questions under the Spiral Analysis Methodology

Key techniques such as experimentation, wargaming, red teaming, modelling and simulation are essential to identify the options for technology insertion, technology-concept development and most importantly the military utility of such technologies. A "FTCE toolbox" of models, simulations, analysis tools and techniques will be developed over time, maximising reuse to increase the analysis tempo. A series of scenarios covering Joint Land operations will need to be developed to underpin studies. While the methodology is not based on specific time-frame, appropriate orders of battle and associated capability databases are in development focussed around the 2025 epoch to confirm the ability of autonomy to have an impact within the current IIP capabilities.

IV. Autonomous Weapon Exploration (AWE)

The first FTCE exploration activity was held in May 2018 at DST Edinburgh as part of the Autonomous Weapon Effectiveness stream. The aim of the activity was to explore the effectiveness, employment and FIC impacts of High-Precision Low-Yield Loitering Munitions (HPLYLM) in single and collaborative modes. The secondary aim of the event was to develop the FTCE methodology and the nascent human-in-the-loop simulation capability within LCA.

The Autonomous Weapon Exploration (AWE) was a 3-day simulation-based exploration experiment investigating the application of autonomous weapons in a battlegroup level urban break-in battle scenario. It explored own force and

adversary technical and tactical responses in the employment of loitering munitions through the planning, execution and analytical review of a series of company/battalion level events.

The activity supports several streams of DST and Army efforts. It will principally inform the DST research program on collaborative and cooperative weapon technologies in understanding their concepts of employment within an operational context. The activity also assists the development of the FTCE programme and methodology. The activity supports Army Innovation Day (AID), Army's Robotics and Autonomous Systems stream and informs project decisions.

A. Experiment Design

The focus of the AWE was to understand the employment of the different autonomous weapons modes and their command and control (C2). The analytical outcomes were to identify the factors influencing this employment, their advantages, disadvantages and opportunities for improvement. The weapon system under investigation was a HPLYLM based on a micro-UAV encompassing both sensor and weapon (generating a grenade effect). Multiple devices were permitted to operate at one time and when utilised in collaborative mode, produced an enhanced blast effect.

The experiment utilised an aggregate computer-based human-in-the-loop wargame (MASA SWORD) to explore use of the weapon system within an urban operational context. Five military personnel participated as commanders and SMEs in the wargame supported by a team of 12 staff.

The experiment was designed for multiple exploration parameters within the limits of capability realities. Three key parameter pairs were explored:

- The specific phases of conventional war:
  Attack (break-in to an urban environment) and Defence of an urban area;
- Different methods of employing the munitions:
  - C2 High: weapon employment controlled at the battlegroup command level;
  - C2 Low: weapon employment controlled at the lowest (platoon/soldier) level; and
- Weapon employment modes (single or collaborative).

Data was collected from analysts, participants and subject matter experts addressing planning, execution, simulation events and post activity discussion. The data collected across the exploration parameters was both qualitative and quantitative.

B. Insights

Analysis of the data captured during the AWE is still being conducted; therefore, limited information concerning findings can be presented in this paper. While the key insights are yet to be determined, three clear observations regarding weapon autonomy were made by the participants:

- Different C2 models generated a different series of HPLYLM functions not originally included in the design intent. Considerable interest was generated in employing the technology beyond its original parameters in the C2 High model;
- Employment of HPLYLM of the scale and capacity envisaged will have significant FIC impacts on Army, particularly in areas of:
  - Training;
  - Command, Control and Communications; and
  - Legal and other Rule of Engagement implications;
- A tension between the autonomous system being utilised by Army as "just another weapon system" and the potential for a significant effect enhancement.

The AWE activity also provided the military participants with exposure to new autonomous weapons capabilities, concepts and tactics development.

V. SUMMARY

Innovation and technology insertion in the ADF and Army is not yet yielding the anticipated results. FTCE is a new programme developed to address this gap through the utilisation of operations and systems analysis. The focus of FTCE is to understand the impact, effectiveness and utility of incoming technologies and their Return on Investment in partnership with military users and technology developers.

The conduct of consecutive and cooperative spirals of analysis will provide the incremental effectiveness understanding necessary to shape the evolution, direction and trade-offs required in innovation development.

As a new initiative the FTCE programme is yet to realise its full potential, however the AWE stream has already shown considerable promise in the demonstrating the usefulness of the FTCE concept and incremental-spiral analysis.

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