Science and Technology Support to Concept Development & Experimentation

Ms. Nathalie Harrison and Dr. Richard Lestage
Defence Research and Development Canada - Valcartier
2459, Boulevard Pie-XI Nord
Val-Bélair (Québec) G3J 1X5
Canada

nathalie.harrison@drdc-rddc.gc.ca / richard.lestage@drdc-rddc.gc.ca

ABSTRACT

Concept Development and Experimentation (CD&E) has been identified as an enabler to armed forces transformation. CD&E relies on integrated and collaborative work in which the Science and Technology (S&T) community is an important player as a source of innovative concepts and technological advances. In order to achieve an efficient synergy, the S&T work should be tailored to the strategic planning needs. Among the different options to anchor S&T with CD&E, Modelling and Simulation (M&S) represents a recognized approach. This paper discusses process and technology issues to transition S&T expertise to better support CD&E activities. It focuses on the capture of Subject Matter Experts' (SMEs) knowledge into models and the leveraging of engineering-level M&S. The investigation has been conducted in the context of a newly created Canadian Air Force CD&E organization. The evaluation of the proposed vision against the CD&E authorities' expectations allows to conclude that M&S technology needs improvement to be fully integrated into derived applications such as CD&E. Therefore, the M&S community must focus on deploying a mature infrastructure to CD&E sites.

1.0 INTRODUCTION

Concept Development and Experimentation (CD&E) has been identified as an enabler to armed forces transformation in NATO countries and particularly in Canada [1,2]. In the defence context, CD&E is defined as the application of the structure and methods of experimental science with the aim of exploring innovative methods of operation, especially to assess their feasibility, evaluate their utility, or determine their limits [3]. CD&E helps to achieve the revolution of military affairs through capability-based planning. The development and experimentation of new concepts is specifically oriented to fill capability gaps.

Each CD&E organization in each country has its own process more or less similar to others. As an example, Figure 1 illustrates a generic CD&E process proposed by Alberts et al. [4]. Generally, CD&E processes rely on integrated and collaborative work inherent to the multidisciplinary implications of CD&E. Among all techniques, Modelling and Simulation (M&S) is recognized as an enabler to achieve cost-effective integration and collaboration. In the Canadian context, the CD&E and M&S coordination organizations were created purposely to follow the recommendation of systematically applying M&S to CD&E [5,6,7].

The Science and Technology (S&T) community is an important player in CD&E as a source of innovative concepts and technological advances. In M&S, the defence technology experts are called Subject Matter

Paper presented at the RTO NMSG Symposium on "Modelling and Simulation to Address NATO's New and Existing Military Requirements", held in Koblenz, Germany, 7-8 October 2004, and published in RTO-MP-MSG-028.

Experts (SMEs). They are individuals who, by virtue of position, education, training, or experience, are expected to have uncommon expertise or insight relative to a particular technical or operational discipline, system, or process, and who has been selected or appointed to participate in development, VV&A, or use of a model or simulation [8]. Herein, SMEs refers to technical SMEs who are doing Research and Development (R&D) within S&T organizations as opposed to operational SMEs who are military operation experts. For example, engineering-level SMEs could be specialists of precision weapon or electro-optical warfare sub-systems.

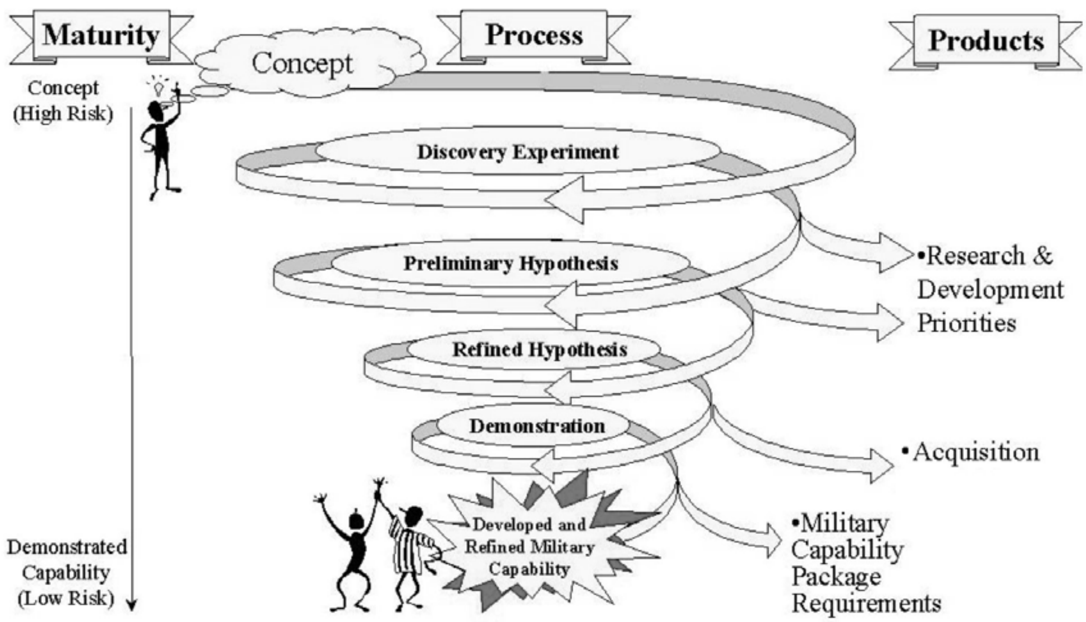

Figure 1: Illustration of a generic CD&E Process [4]

In order to achieve an efficient synergy between the new defence requirements and the deliverables of S&T organizations, the R&D work should be tailored to the strategic planning needs. Since this aspect of CD&E is scarcely detailed in CD&E organizations Concept of Operations (CONOPS), this paper will address the transition of S&T expertise better support CD&E activities. It will focus on how to leverage engineering-level knowledge and how to efficiently use S&T progress and evaluate its potential benefits on future capabilities. The objective is not to define another CD&E process, but to improve the relationship between CD&E organizations and the S&T SMEs. In the context of engineering-level S&T contribution, concept refers herein to operating and functional future military concepts [9].

The next section will discuss how S&T activities can be tailored to efficiently support CD&E by doing the right R&D. Section 3 will state the challenges in determining S&T contribution to CD&E. Section 4 will detail the required process and technology characteristics for S&T support to CD&E. The investigation will be based on the capture of SMEs' knowledge into models and the leveraging of engineering-level M&S. Section 5 will point out the lessons learned in the investigation of S&T support to CD&E for the Canadian Forces Aerospace Warfare Centre (CFAWC). Finally, Section 6 will summarize the progresses in S&T support to CD&E and introduce the way ahead.

2.0 THE RIGHT R&D

The interaction between S&T and CD&E organizations is generally stated in a passive form like: "coordinate with the S&T organization to ensure reports, recommendations and observations are accessible and applicable to the military units" [10]. In one Canadian initiative, a capability transition groups has been posted on an S&T site to give feedback on new technologies to the Canadian Forces. However, it is believed that a more proactive innovation scheme would be most desirable to efficiently accomplish the armed forces transformation [5].

The methodology underlying to this paper implements a so-called fourth generation R&D approach [11]. Defining the process and the technology to enable S&T support to CD&E is, in fact, to conduct R&D on how to do R&D. One major change in doing R&D would be to systematically align deliverables to strategic planning needs. This would ensure a higher transfer ratio from the S&T to the CD&E community. The usual continuous innovation, which is technology-pushed, would then be replaced by discontinuous innovation, which will be capability-driven. Mastering this linkage between strategy, innovation and R&D will foster the armed forces transformation.

3.0 DEFINING S&T CONTRIBUTION TO CD&E

Several challenges arise when trying to isolate the S&T contribution to CD&E. In the CD&E process, the engineering-level knowledge needs to pass through several layers, from models to simulations, experimentations and analyses. Beyond the challenge to perform the right R&D, the engineering-level SMEs must ensure to produce usable outcomes, while input and output requirements transit through multiple contributors. In this case, roles and responsibilities can become so confused through the various layers that the SMEs' contribution can be inadvertently bypassed. Consequently, this paper proposes some solutions to take into account the engineering knowledge in the CD&E process to give access to the full range of potential concepts and to ensure their technical validity. Discussions with stakeholders led to the observation that disconnections between the S&T and the CD&E communities occur at the procedural and technical levels.

3.1 Procedural Challenges

Procedural challenges refer to the difficulties that arise from the intrinsic ways of doing R&D and CD&E or from the internal processes of the corresponding organizations. The main obstacles that were observed are listed below.

- Each contributor to CD&E has its own roles, responsibilities and mandates that are translated into its processes and CONOPS. The collaborations with other organizations are generally stated in a vague manner, leading to overlaps or gaps of roles, responsibilities and mandates. In some cases, too many people are coordinating and, in other cases, to few are coordinating.
- The long term nature of R&D projects implies a slow iteration rate that is not be appropriate to CD&E, where rapid feedback is required to allow for timely convergence despite the fuzzy requirements available.

- The interaction with SMEs, as conceived by most CD&E organizations, requires the posting of a few SMEs on the CD&E teams. However, it is hard to attract SMEs for a term that may not be entirely in line with their career advancement [12]. Furthermore, it does not necessarily give access to the full extent of available expertise. Therefore, different ways of proceeding should be institutionalized. Both operating processes and administrative mechanisms should give flexible access to SMEs, above the regular service-level-agreement, for punctual needs over a long-term continuous support.

Theses challenges influence the process for S&T support to CD&E. Since both parties have their limitations, it would imply an adaptation on both sides to first formulate the request and then deliver the answer into a usable format.

3.2 Technical Challenges

Technical challenges refer to the technology limitations preventing the immediate and natural connection between S&T SMEs and CD&E. The challenges identified within the context of the current study are listed below.

- Little common infrastructure, interfaces, tools and practices can support a persistent collaboration.
- Traditionally, CD&E is associated to operational research and war gaming. The M&S techniques used may require an adaptation to efficiently integrate engineering-level knowledge.
- Engineering-level SMEs' knowledge is generally captured ad hoc, without consideration for reusability benefits such as time and cost saving for designing a new experiment.
- The various CD&E techniques may require different levels of knowledge. The challenge is to determine what level is appropriate in each case. SMEs' role varies from one CD&E activity to another. Therefore, it becomes difficult to standardize a technology since the representation changes with the knowledge level to be delivered. This representation can take the form of the simple capture of conceptual knowledge in a conceptual model of the battle space. It could be a problem-tailored representation such as a parametric set for requirements simulation or a high-fidelity physics-based model. It could also take the form of a traditional publication or the independent validation of someone else's design. Figure 2 shows a representation of the M&S formulation space for experimentation.

Theses challenges influence the technology chosen to implement S&T support to CD&E.

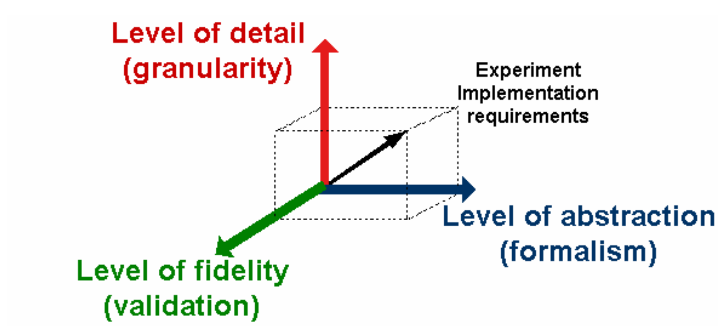

Figure 2: The M&S formulation space for experimentation

4.0 PROCESS AND TECHNOLOGY FOR S&T SUPPORT TO CD&E

In response to the challenges identified previously, requirements were derived to characterize the process and the technology to be implemented for S&T support to CD&E.

4.1 Process for S&T Support to CD&E Implementation

The process for S&T support to CD&E must be embedded into the CD&E process and specify standard interfaces for systematic interaction between the two organizations. Therefore, the two major requirements for these interfaces are, at the input, to request for SMEs to address a particular capability gap, and at the output, to reply in an appropriate format. Figure 3 illustrates these interface requirements.

The resulting process is based on two basic principles: the proactive interaction between the two communities shall be initiated at the military requirements level and the engineering-level community shall comply with the higher-level perspective of the CD&E community. This is particularly true when M&S is the interchange format and both parties have to agree on a position within the M&S formulation space for experimentation. These two principles directly influence the input and the output of the interaction process. The input to R&D work is either the areas of improvements identified by the strategic analysis groups or some pre-identified concepts. The output deliverable to CD&E is a simple idea or a detailed concept formulated to be readily usable for CD&E. In between, SMEs shall adopt compliant internal practices to solicit, develop, capture and transfer knowledge.

Figure 3: Process interfaces for S&T support to CD&E

Furthermore, this process must be based on continuous support and long-term proactive collaboration. It must also undergo rapid iterations to compensate for the new concept requirement unknowns and to ensure timely convergence at the time scale suitable for CD&E needs as opposed to the slower R&D time-scale.

The proposed process could be categorized as an Integrated Concept Team (ICT) [13] that has to support the distributed location of the participants and continuous and iterative requests and replies. Figure 4 illustrates the interactions occurring during the proposed process.

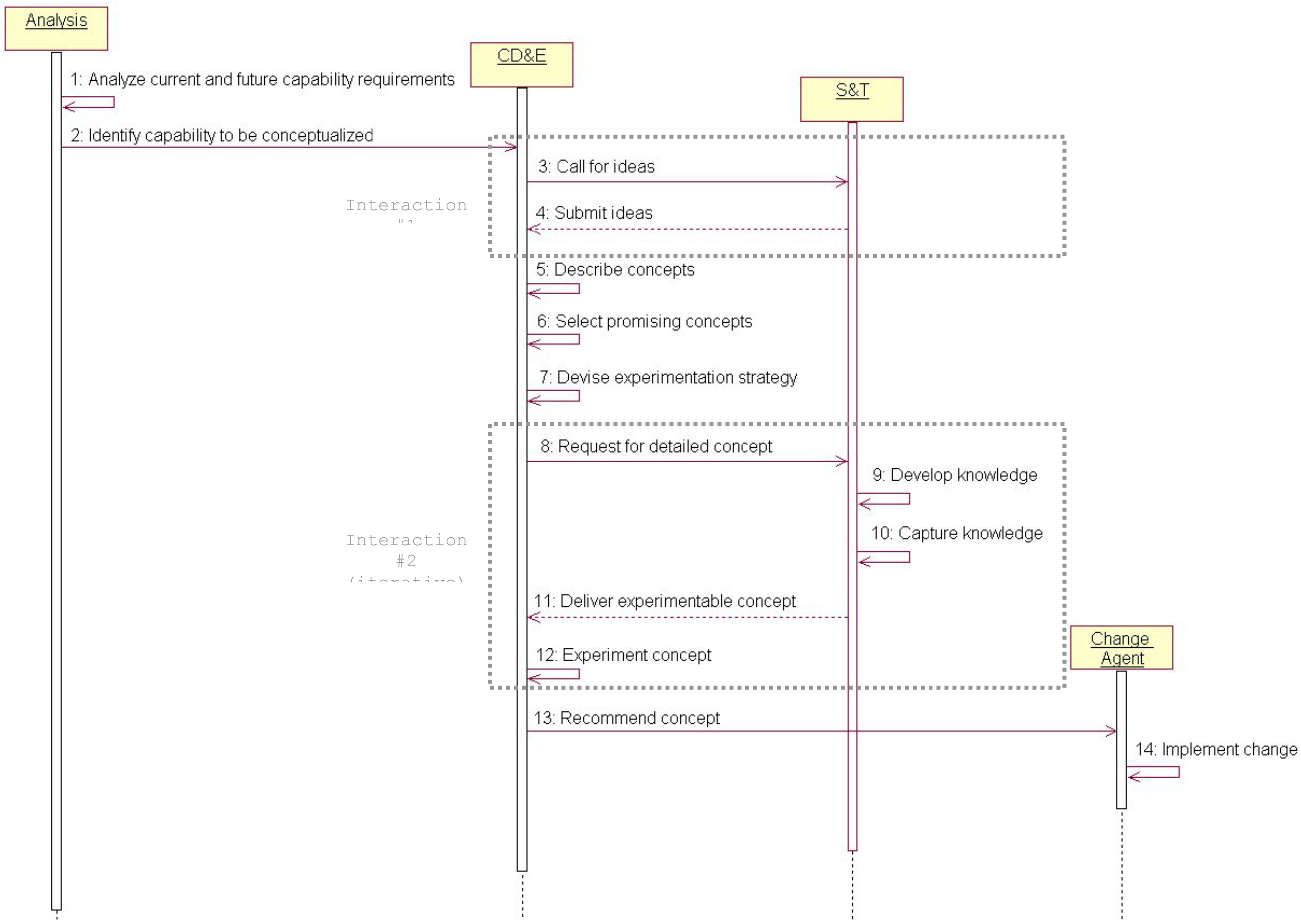

Figure 4: Process for S&T support to CD&E

Based on investigations underlying this paper, the process for S&T support to CD&E shall meet the following basic criteria.

- First, the process requires a preliminary identification of capability gaps such as devised by a capability engineering process. In Canada, an initiative on Collaborative Capability Definition, Engineering and Management (CapDEM) [14] is intended for that task during the acquisition process. It is believed that a similar approach could help CD&E organizations to better identify areas of improvement.
- The process must start with a formal "call for ideas" to bring SMEs to contribution using, for instance, a broad communication method such as a collaborative engineering environment portal. In order to work proactively, the SMEs need to be aware of the preoccupations of the CD&E teams. The first interaction concludes with the submission of ideas.
- Once the CD&E team has selected the pertinent ideas to undergo a detailed concept development and once they have devised the experimentation plans, the SMEs areas of contribution as well as their level of interaction must be defined. The request must include the acceptation requirements, the knowledge transfer format, the required responsiveness, the required iteration cycles, the required

persistence of the deliverable, etc. A standard format for acceptation criteria is the VV&A accreditation requirements report [15] that must be completed by the requestor on the CD&E side.

- The second interaction starts on receipt of the request for detailed concept development. The S&T SMEs must apply a rigorous modelling methodology to efficiently develop and capture the required knowledge in a format compliant with the selected experimentation technique. Such a methodology to capture SMEs' knowledge in a living format and to leverage engineering-level M&S has been demonstrated previously [16]. The deliverable must meet the accreditation requirements and be produced timely in a readily usable format.
- The CD&E team is responsible to experiment with the concepts and to ask for iterative refinements. Afterwards, the CD&E team transfer the recommended concept to an implementation authority.
- Finally, the process must also cope with inter-organizational and administrative issues. The necessary steps for mandate creation and financing must be included to closely follow the pace of the continuous collaboration.

4.2 Technology for S&T Support to CD&E Implementation

In response to the observations made within the Canadian context, the technology able to support a continuous proactive collaboration between the ICT members requires the following features.

- The supporting technology must integrate technical and logistic infrastructures to keep the whole process at an acceptable speed.
- The infrastructure must provide persistent collaboration to ensure responsive interaction with SMEs. In practice, the infrastructure will be scaled overtime to accommodate CD&E projects, but a minimum infrastructure must be settled prior the first use of collaborative M&S in CD&E. In theory, this responsibility relies on M&S coordination resources. However, as early users, CD&E resources will participate in the elaboration of the basic infrastructure.
- The infrastructure must be adaptive and flexible to accommodate the various interaction levels appropriate for each experimentation type and to maximize reuse between experimentation levels.

Figure 5 illustrates the global infrastructure proposed to support the S&T collaborative work within CD&E. A possible implementation of this infrastructure could be a web-based collaborative development tools to support the persistent and iterative interchange process between the participants. The request and reply administrative mechanisms should also transit through the web portal to meet time requirements. A current Canadian initiative in that direction involves the use of virtual teamwork for collaborative capability development [17].

From the CD&E perspective, the use of a modern simulation technology, such as a persistent and extensible synthetic environment, can significantly reduce the time to set up an experiment. For example, the Canadian Advanced Synthetic Environment (CASE) [18] and the US Joint Distributed Continuous Experimentation Environment (DCEE) [19] are initiatives where the need for a standing simulation infrastructure has been identified. Their technical framework would also benefit from being connected to the collaborative environment. They could envision to perform web-based simulation as proposed by the Extensible Modelling and Simulation Framework (XMSF) initiative [20], which is a step further than the High Level Architecture (HLA) and the Federation Development and Execution Process (FEDEP) in terms of reusability and persistence [21].

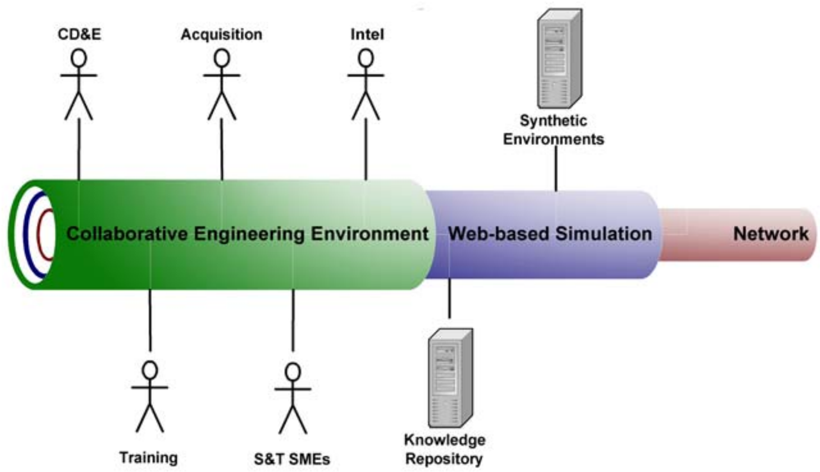

Figure 5: Technological infrastructure for S&T support to CD&E

From the S&T SMEs perspective, an integrated suite of tools [16] from conceptual modelling to synthetic environment components generation would allow to comply with the engineering-level practices on one side and to deliver the expertise in usable format for CD&E on the other side. Since the same knowledge can be required in different formats for different experimentations, the methodology and the infrastructure implement the Model-Driven Architecture (MDA™) [22,23]. SMEs will benefit from the use of MDA™ to ensure a reasonable return on their M&S investment and to remain responsive to their various clients. According to the MDA™, the reusable part of the knowledge can be captured in a conceptual model of the mission space where both technical and operational SMEs agree on a common body of knowledge that is reusable whatever the implementation, the scenario or the experiment. However, several issues remain to combine very different models in the same framework (multi-modelling) and to capture very different knowledge and translate it into usable models (multi-formalism modelling).

5.0 S&T SUPPORT TO CANADIAN AIR WARFARE CD&E

The work presented in this paper is conducted in the context of the newly created CFAWC as the Tier-3 [5] portion of CD&E for the air environment. It was timely to include a proactive S&T support to air warfare CD&E during the writing of their CONOPS [10] and Master Plan [24]. The definition of a process and technology for S&T support to CD&E is only the definition phase of a larger initiative towards a virtual air mission capability. Such a synthetic environment would be the integrating technology for maximizing the M&S return on investment for CD&E as well as other Simulation and Modelling for Acquisition, Requirements and Training (SMART) activities.

This research is conducted from the perspective of engineering-level M&S SMEs. Discussions with air warfare authorities revealed their real concerns on the subject of S&T support to CD&E as listed below.

- The main mandate of a CD&E organization is to produce capability and its work must lead to concept implementation, whatever the mean or technique used to achieve it.
- Because of limited resources to perform the main mandate, the level of involvement into related domains, such as capability requirements and M&S, must be prioritized.

- From the CD&E perspective, M&S is essentially a mean to reduce force generation cost.
- Joint interoperability is an essential requirement and any coordination initiative is welcome if it is sound with the CD&E mandate.
- A CD&E organization relies on major projects to build the persistent synthetic environment infrastructure, such as the CASE initiative in the Canadian Air Force.
- The use of M&S to achieve valuable outcome must be demonstrated.
- Operational researchers are well positioned into the CD&E teams to help involving the technical SMEs in the CD&E process.

One lesson learned from the discussions with CD&E authorities is that M&S must continue to evolve to better satisfy the needs. The body of knowledge of M&S has greatly improved over the last decade but few efforts have been dedicated to what matters the most to M&S users: metrics; Verification, Validation and Accreditation (VV&A); and a readily deployable infrastructure.

The investigation brought the following question: "What can engineering-level SMEs do right now for S&T support to CD&E?" In practice, it would be difficult to institutionalize a process for S&T support to CD&E because the underlying technology is not mature. However, populating the air warfare virtual battle space to build the basis of an infrastructure seems to be the logical first step. The rapid deployment of a functional infrastructure will help to promote the vision of an optimal S&T support to CD&E.

6.0 CONCLUSION

In summary, this paper discussed the rationale for a formal S&T support to CD&E. The CD&E being a response to the armed forces transformation requirement, it is logical to apply the same capability-driven philosophy to R&D activities. Tailoring R&D can optimize the synergy between CD&E and S&T organizations. However, current gaps in procedures and technologies must be overcome to realize that vision. The process to implement S&T support to CD&E must break the barrier between organizations. The request and reply interfaces must specify technical details as well as administrative mechanisms. The underlying technology must settle the technical framework for continuous collaboration through the capture of SMEs knowledge into models for simulated experimentations. Beyond the analytical work, collaborative work is essentially based on goodwill of individuals supported by organizational good practices. Therefore, processes and technologies are not an end but only a mean to achieve S&T support to CD&E.

This initiative offers the advantage to rally the engineering-level community to become more responsive to the armed forces quest for innovation. With the formal involvement of S&T in CD&E, SMEs would be ready to rapidly convert a concept into a capability. A systematic process for consultation of SMEs would result in a more rigorous decision-making, risk mitigation, money and time saving.

However, in practice, CD&E organizations have many different concerns requiring significant resources. CD&E is a complex issue and it implies prerequisite technology to be settled. De facto, it needs a reliable M&S-based collaborative environment.

It is believed that the M&S community must focus on delivering a readily deployable infrastructure to support CD&E activities. If the infrastructure framework is scalable and extensible, it can be deployed early and timely and continue to evolve as the CD&E projects go along. The development should focus on the gain of maturity of the M&S body of knowledge in terms of metrics, VV&A and deployment readiness, which are mandatory prior the adoption of M&S by the client. The role of engineering-level SMEs is to populate the framework with fundamental conceptual knowledge reusable in different scenarios within rigorously defined validity bounds.

A similar argument is applicable for the SMART application. Applications can barely be evaluated if no infrastructure is first deployed. Moreover, the advances in both CD&E and SMART applications can be leveraged to the other application if joint coordination, commonality and interoperability are well established.

7.0 REFERENCES

[1] Operational Working Group (1999). *Canadian Defence Beyond 2010: A Way Ahead*. http://www.vcds.forces.gc.ca/dgsp/00native/rep-pub/dda/rma/wayahead/rma2010_e.pdf

[2] Canadian Forces and Department of National Defence (1999). *Shaping the Future of Canadian Defence: A Strategy for 2020*. http://www.cds.forces.gc.ca/pubs/strategy2k/intro_e.asp

[3] Davis, R. (2002). *Concept Development & Experimentation*. System Engineering and Test and Evaluation Conference 2002, Sydney, Australia. http://www.seecforum.unisa.edu.au/sete2002/ProceedingsDocs/65S-Davis.pdf

[4] Alberts, D.S., Hayes, R.E., Wells, L. & Stenbit, J.P. (2002). *Code of Best Practices for Experimentation*. US DoD Command and Control Research Program. http://www.dodccrp.org/publications/pdf/Alberts_Experimentation.pdf

[5] Symposium Working Group (2000). *Creating the Canadian Forces of 2020: A DND/CF Concept Paper on Concept Development and Experimentation and Modelling and Simulation*. http://www.vcds.forces.gc.ca/dgsp/00native/rep-pub/dda/symp/cde/conceptpapr_e.pdf

[6] Symposium Working Group (2000). *Modelling and Simulation: Enabling the Creation of Affordable, Effective 2020 Canadian Forces*. http://www.drdc-rddc.dnd.ca/seco/documents/Modeling_and_Simulation_Discussion_Paper_e.html

[7] Landolt, J.P. & Evans, J.R. (2000). *Air-Systems Capability Modernization Using Modelling and Simulation*. Defence R&D Canada Technical Report No. TR-2000-001.

[8] Pace, D.K. & Sheehan, J. (2002). *SME/Peer Use in M&S V&V*. Foundations'02 V&V Workshop, Laurel, MD, USA.

[9] Schmitt, J.F. (2002). *A Practical Guide for Developing and Writing Military Concepts*. Defense Adaptive Red Team Working Paper 02-4, Hicks & Associates, Inc., McLean, VA, USA. http://www.dtic.mil/jointvision/dart_guide.pdf

[10] Chief of Air Staff (2003). *Canadian Forces Aerospace Warfare Centre Concept of Operations*.

[11] Miller, W.L. & Morris, L. (1999). *Fourth generation R&D: Managing Knowledge, Technology, and Innovation*, Toronto: Wiley.

[12] Hazen, M.G., Graham, A. & Shurson, A. (2004). *Maritime Concept Development and Experimentation: Options for Implementation*. Defence R&D Canada – Atlantic Technical Report No. TR-2003-066. http://cradpdf.drdc-rddc.gc.ca/PDFS/unc23/p521688.pdf

[13] US Department of Defense (1997). *Army Science and Technology Master Plan: Science and Technology Integration With Army XXI Requirements Determination*. http://www.fas.org/man/dod-101/army/docs/astmp/index.html

[14] Pagotto, J. & Walker, R.S. (2004). *Capability Engineering – Transforming Defence Acquisition in Canada*. Proceedings of Defense and Security SPIE Conference 2004, paper No. 5441-21.

[15] Canadian Department of National Defence Synthetic Environment Coordination Office (2003). *Modelling and Simulation Verification, Validation and Accreditation Guidebook*. http://www.drdc-rddc.gc.ca/seco/documents/VVA_Guidebook_DND_SECO_May_2003_e.html

[16] Harrison, N., Gilbert, B., Lauzon, M., Jeffrey, A., Lalancette, C., Lestage, R. & Morin, A. (2002). *A M&S Process to Achieve Reusability and Interoperability*. Proceedings of the NATO RTO M&S Conference 2002, RTO-MP-094, 11.1-11.18. ftp://ftp.rta.nato.int/PubFullText/RTO/MP/RTO-MP-094/MP-094-11.pdf

[17] Waruszynski, B.T. (2004). *Enabling Collaborative Capability Through Virtual Teamwork: The Way Ahead*. Defence R&D Canada – Ottawa Technical Memorandum No. TM-2003-217. http://cradpdf.drdc-rddc.gc.ca/PDFS/unc21/p521221.pdf

[18] Thompson, R. (2004). *The Canadian Advanced Synthetic Environment" – Creation of a distributed simulation environment to support Air Force MA&S activities*. JSMARTS Vision Workshop, Ottawa, Canada. http://admmatapp.dnd.ca/cosmat/dmasp/downloads/ModellingSimulation/Presentations/Thompson.ppt

[19] Ceranowicz, A., Dehncke, R.W. & Cerri, T. (2003). *Moving Toward a Distributed Continuous Experimentation Environment*. Interservice/Industry Training, Simulation, and Education Conference 2003, Orlando, FL, USA. http://www.alionscience.com/pdf/Dist_Environment.pdf

[20] Extensible Modeling and Simulation Framework (XMSF) web site: http://www.movesinstitute.org/xmsf/

[21] Tolk, A. (2002). *Avoiding another Green Elephant – A Proposal for the Next Generation of HLA based on the Model Driven Architecture*. 2002 Fall Simulation Interoperability Workshop, paper No. 02F-SIW-004. http://www.omg.org/mda/mda_files/02F-SIW-004-OMG.pdf

[22] Harrison, N., Gilbert, B., Jeffrey, A., Lauzon, M. & Lestage, R. (2004). Adaptive and Modular M&S Configuration for Increased Reusability. Interservice/Industry Training, Simulation and Education Conference 2004, Orlando, FL, USA.

[23] Model Driven Architecture (MDA^{TM}) web site: http://www.omg.org/mda/

[24] Chief of Air Staff (2004). *Master Implementation Plan for the Canadian Forces Aerospace Warfare Centre*.