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# Operational Art Support

*STI Assessment 7830*

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Contract number : SDA-07-001-021

Contract Scientific Authority: Micheline Bélanger, Defence Scientist



## Defence R&D Canada – Valcartier

Contract Report
DRDC Valcartier CR 2011-619
October 2011

Canada

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# STI Assessment

| | |
|---|---|
| **Product / Title** | **Operational Art Support** |
| **Project Numbers** | STI 7830, DRDC SDA 07-001-021 |
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# 1 SUMMARY

This literature survey is intended to assist DRDC researchers to determine R&D trends in military operational planning and to assess potential tools or models in support of operational art. In addition to a short review of selected doctrinal documents and recent discussion papers in the field, we retrieved 325 publications on operational planning tools, which formed the basis for a bibliometric assessment of R&D trends in tools development.

Generally, it was found that the operational planning aspect most supported by planning tools is course of action analysis - usually involving scenario generation, war gaming or other simulations. Some element of risk analysis is also reported, as well as conceptual graphs or other graphical representations and decision aids such as scorecards for presenting and quantifying alternative courses of action.

While the Canadian Forces have not yet adopted concepts of effects-based operations or operational design into doctrine, it is clear that these concepts are influencing doctrine in other countries and the development of associated tools. Elements that may influence tools development and that should be monitored for new developments are the following:

- Tools should facilitate creativity and non-linear planning approaches, allowing more space for humans-in-the-loop;
- Planning processes may place more emphasis on framing the problem, causal analysis and on iterations in problem development;
- Tools should be adaptive and provide for modeling and simulation of multiple scenarios or courses of action;
- Tools should employ multiple models and agents that introduce elements of PMESII (social science models), as well as including non-military instruments (DIME) in the courses of action;
- The identification of centres of gravity and decisive points remain important in all doctrine, but there should be emphasis on critical factors analysis through the CV-CR construct.

This report focuses on military planning tools, but parallels in other industries have been identified, such as software release planning, strategic business planning (especially scenario generation), and space missions planning. Details on 14 planning tools are provided with this report.

Major players in tools development include primarily US military organizations or their academic partners. The top five organizations, by numbers of publications are:

- US Air Force Research Laboratory (AFRL), Rome, NY (20 publications)
- Naval Postgraduate School, Monterey, CA, USA (17)
- Defence Science & Technology Organization (DSTO), Australia (12)
- George Mason University, Fairfax, VA, USA (10)
- US Army Command and General Staff College, Fort Leavenworth, KS (10).

# 2 BACKGROUND

## 2.1 Context

Military operational planning for command and control uses structured, methodical procedures such as those detailed in the Canadian Forces Operational Planning Process (CFOPP). This process and others like it[1] are designed to identify critical capabilities (essential conditions, resources, and means as well as vulnerabilities) for both friendly and opposing forces. The outcome is a high level plan that informs subsequent decisions, courses of actions and execution. The CFOPP does not encompass tactical planning or actual detailed execution; instead, the emphasis is on team orientation, risk management, criteria management, and decision making in support of both anticipated events and developing crises.

In planning operations, the Canadian Forces must work with other government agencies and coalition partners, often in complex, asymmetric environments and at multiple levels of command. To meet the challenges posed by this complex planning environment, DRDC Valcartier would like to investigate complementary options and approaches[2] that may offer additional flexibility, speed, adaptivity and agility, while still meeting core requirements. These approaches might consist of models, processes and tools for high level operational planning, but they need not be confined to the military domain. Any discipline that uses a complex systems approach to operational planning in a dynamic environment, such as logistics, space mission planning, disaster relief, or healthcare, may also provide insights, tools, and alternative approaches.

## 2.2 Key Issues

DRDC Valcartier wishes to explore complementary approaches and support tools for the operational planning process. To do so, they have commissioned a review of scientific and technical literature, patents, and methods/tools adopted by other defence agencies and sectors engaged in the planning of complex operations. The research strategy should focus on military environments (i.e., collaborative, multilevel, anticipatory as well as rapid response, symmetric as well as asymmetric) but may also investigate approaches used in other sectors where conditions are complex, dynamic, and distributed.

Results of this Strategic Technical Insights (STI) assessment will allow DRDC researchers to determine R&D trends and players and also to assess potential tools or models in support of operational art.

[1] Such as center of gravity analysis, decisive point analysis, NATO's TOPFAS planning tool.
[2] Such as intuitive decision making [expert teams], effects based approach to operations (EBAO), analytic or naturalistic (non-linear) approaches such as the Israeli Defence Force's Systemic Operational Design

## 2.3 Key Questions

1. What are the emerging trends (theories, models, concepts) for complex operational planning?
2. What are the known tools (software, platforms and processes) in support of operational planning?
3. Who are the major academic, government and industry players in this domain worldwide? What are their areas of expertise?
4. Who are the leading experts (individuals) in this field worldwide and what are their areas of expertise? Who are the leading Canadian experts and what are their areas of expertise?

# 3 FINDINGS

## 3.1 Trends in Operational Planning

### 3.1.1 Concepts and Theories

The purpose of the following section is to provide an overview of current theories, models and concepts in military operational art so that appropriate tools may be developed in support of complex operational planning. This section is not meant to be an evaluation or discussion of the merits of those theories and current military doctrine, but to summarize and highlight those concepts currently generating significant discussion in the literature and point to additional sources the reader may consult for further information. Section 3.1.2 provides more details and discussion of the associated analytical methods that may be incorporated into planning tools.

The primary operational art concepts that are receiving recent attention in the literature and that will be discussed below are:

- Effects-based operations
- Systemic Operational Design
- Wicked or “ill-structured” problems
- Operational Design (US Version)
- Critical vulnerabilities

**Operational Art**

There are four levels of planning according to Canadian doctrine: government policy, strategic planning, operational planning and tactical planning. Operational planning is the process to translate strategic direction, set by the government, into mission and tasks for subordinate, tactical level commanders (Chief of the Defence Staff 2008). Operational art and operational planning are not synonymous, but they are inextricably linked:

> Operational art is the application of creative imagination by commanders and staffs – supported by their skill, knowledge and experience – to design strategies, campaigns, and

> major operations and organize and employ military forces. Operational art integrates ends, ways, and means across the levels of war. It is the thought process commanders use to visualize how best to efficiently and effectively employ military capabilities to accomplish their mission (Wade 2009, 3-27).
>
> Art is defined as, "The skill of employing military forces to attain strategic objectives in a theatre of war or theatre of operations through the design, organization and conduct of campaigns and major operations." (source – DTDB) (Chief of the Defence Staff 2008, 1-3).

Operational art, as pointed out in the Canadian Forces Operational Planning Process (CFOPP) is not synonymous with the operational level of war; rather it refers to the skill and ingenuity of the commander to translate strategic direction into tactical action. The methods and tools that the commander and staffs may use to accomplish this task are the focus of the present study.

There are some basic elements or concepts of operational planning that are variously discussed in the literature (see Lessard's list (p.4) of naming conventions across jurisdictions (Lessard 2004)) and must be understood for this study. The elements most associated with the planning stage of a campaign are: end states, centres of gravity, decisive points, lines of effort and lines of operation. Rather than define these elements here, we assume that the recipients of this report already understand these concepts. For precise definitions, readers should refer to the Canadian Forces Operational Planning Process (Chief of the Defence Staff 2008) or the US Joint Operational Planning manual, known as JP-5 (Joint Chiefs of Staff 2011).

Our review of operational art theory shows that there is a great deal of discussion in the literature about approaches to operational planning, such as effects-based planning and systemic operational design but there is also a great deal of variance in the application of these theories. The Canadian Operational Planning Process (CFOPP) document, released in 2008 is quite clear about the Canadian Forces (CF) position on them:

> To be clear, the basic principles of OPP remain unchanged [since 2002]. Although there has been much recent discussion concerning new planning concepts such as Strategic [sic] Operational Design and the Effects Based Approach to Operations, these concepts are not yet mature enough to be written into doctrine (Chief of the Defence Staff 2008, i).

In the United States, on the other hand, there has been a great deal of evolution in planning doctrine over the past few years, going from a complete adoption of Effects-based operations (EBO) (also sometimes also referred to as effects-based planning) to a newly released doctrine of "operational design", which appears to be a hybrid of EBO and systemic operational design (SOD). Here follows a brief discussion of these concepts.

**Effects-based operations (EBO)**

William Gregor provides an excellent overview and discussion of the evolution of EBO in US military doctrine, as well as different approaches adopted in Australia and the development of Systemic Operational Design (SOD) in Israel (Gregor 2011). Gregor describes EBO as an approach to operational problems from a holistic systems perspective that employs an iterative cognitive process, variously named: design, the adaptation cycle, and the effects-based approach to operations (EBAO). The effects-based approach had four primary components: knowledge superiority, an effects-based planning process, dynamic execution, and accurate, timely effects assessment. These components were supported by operational net assessment (ONA) to provide knowledge superiority and system of systems analysis (SoSA). Also according to Gregor, SoSA required an understanding of an adversary's political, military, economic, social, information systems and the associated infrastructure (PMESII). Actions could be taken to influence behaviour in the system to promote achievement of outcomes (effects), but these were not strictly military and were to involve all the elements of national power: diplomatic, information, military, and economic (DIME) (Gregor 2011). In the literature gathered for this study, there is ample evidence that EBO has had influence on tools development.

The controversy over EBO and its implications on tools development are discussed in a RAND publication of 2007 (Davis and Kahan 2007, see pp. 59-69). Where the controversy seems to arise is in confusion over the language of effects and the already well understood concepts of end states, objectives, and actions. As Gregor describes it:

> Campaign objectives and strategic objectives were to be understood as effects and the knowledge of the adversary nodes related to those effects were to indicate what actions were needed… An effect differs from an endstate only in the fact that the final condition (the endstate) must be the result of direct or indirect actions. Consequently, greater attention must be paid to: how well specified actions are performed; measures of performance and whether those actions actually produced the condition sought; and measures of effectiveness (Gregor 2011, 101).

In the wake of criticisms of EBO from Marine and Army officers, in 2008 General James Mattis wrote: "Effective immediately, USJFCOM will no longer use, sponsor, or export the concepts related to EBO, ONA and SoSA in our training, doctrine development, and support of JPME [joint professional military education]" (Mattis 2008). As we shall see, however, many elements of EBO, such as better understanding of PMESII and DIME, and incorporating measures of effectiveness, still remain. Elements of SOD (discussed below) also appear to have influenced current US doctrine, in what is now being called "Operational Design".

We did not extensively review Australian or UK doctrine for this paper, but according to Gregor, effects do form part of British doctrine, which in turn informs NATO doctrine and there are parallels in EBO concepts and the Australian Adaptation Cycle. References to current planning doctrine documents are provided in section 6.3 of this report.

**Systemic Operational Design (SOD)**
This theory was developed in Israel and is well described and discussed by Gregor (Gregor 2011), Canon (Canon 2009), Schmitt (Schmitt 2006) and others (see Canon's bibliography). Certain elements of SOD that differentiate it from other theories are:

- that it offers the potential for the military to provide input ("control" according to Gregor) to policy discussion;
- it places a great deal of emphasis on problem definition;
- it is less focused on achieving a desired end state but rather emphasizes learning, adaptation and discourse to develop appropriate courses of action.

For a Canadian perspective on SOD and how it might be incorporated into the CFOPP, see the 2009 article *Systemic Operational Design: Freeing Operational Planning from the Shackles of Linearity* (Lauder 2009).

**Wicked Problems**
As discussed earlier, the SOD places a great deal of emphasis on defining the problem – and our review of the literature confirms that this is an important discussion currently taking place in the operational planning literature. Kalloniatis et al. (Kalloniatis, Macleod et al. 2009) provide some background to the concept of "wicked problems", a term first coined by Rittel and Webber in 1973 (Rittel and Webber 1973). There is no concise definition of the term, but essentially these are planning problems which do not yield to traditional "scientific bases" for problem solution. Kalloniatis et al provide the following concise list of the characteristics of Wicked Problems:

1. *Development of candidate solutions reveals further aspects of the problem.*
2. *Wicked problems have no stopping rule: correct solutions cannot be identified*.
3. *Solutions to Wicked problems are not simply right or wrong.*
4. *Every Wicked problem is essentially unique and novel.*
5. *Every solution to a Wicked problem is a 'one-shot operation.'*

The ways that Wicked Problems parallel military planning problems is that they are complex, open-ended, non-linear, rapidly changing, and subject to many influences and sources of interactivity. Perhaps the most crucial parallel of wicked problems to military operational planning is the first point, where solutions may reveal further aspects of the problem. As Kalloniatis et al describe it: "For Wicked Problems, multiple backtracking, problem restatements in the light of partial answers and even jumps forward to trial solutions are intrinsic to the solution process" .(Kalloniatis, Macleod et al. 2009, 4). For these authors, and others that they cite, the solution for dealing with wicked problems is creative thinking combined with organisational adaptability. Wicked problems are also sometimes referred to as "ill-structured" problems, as described in a 2009 article that relates the concept to US joint doctrine and campaign design (Greenwood and Hammes 2009). The authors state that "understanding the problem and conceiving a solution are identical and simultaneous cognitive processes." They also emphasize that few ill-structured problems are military-centric in nature and that "not every campaign will be exclusively focused on organizing and employing military forces… any effective plan must integrate political, economic, diplomatic, informational and cultural power into a national or even international campaign."

**Operational Design (US version)**
In October 2009, General Mattis issued a memo to US Joint Forces Command entitled *Vision to a Joint Approach to Operational Design* (Mattis 2009). In this memo, Mattis outlines his vision for the new concept of Operational Design and outlines doctrinal changes that were to follow in updates to the JP 5-0 *Joint Operation Planning*. Interestingly, the new doctrine places particular emphasis on understanding the problem:

> Some irregular warfare circumstances can be extremely complex and their operational and strategic objectives more difficult to achieve than those of traditional military operations. The initial observable symptoms of a crisis often do not reflect the true nature and root cause of the problem, so commanders and staffs must devote sufficient time and effort to correctly frame the problem before devising a detailed solution. Getting the context right as early as possible helps the commander attack the right problem (p.3).

In addition to understanding and framing the problem, the other crucial aspects of Operational Design are:

- Understanding the Operational Environment - derived from the Joint Intelligence Preparation of the Operational Environment (JIPOE) process
- Developing an Operational Approach – Lines of effort and lines of operations are not the only ways to depict the approach, though he is not specific about other options. This step also includes the development of indicators of progress and the inclusion of other agencies and multinational partners when necessary.
- Reframing the problem – as the operational environment changes, so there must be a continuous assessment of results in relation to expectations followed by modification of both the understanding of the situation and subsequent operations accordingly.

A careful review of the 2011 edition of JP 5-0 would reveal how much this guidance was actually incorporated into doctrine, however from this short list, we can see that elements of EBO (focus on context, PMESII and DIME, indicators and performance measures) and of SOD (problem definition, reframing the problem), have been incorporated into the US military's approach to operational planning. A review of the executive summary of the JP 5-0 shows that defining the problem remains a critical aspect of design, as does understanding the operational environment. The document also talks about military end states, objectives, effects, and centres of gravity (see pp. xxi-xxii of JP 5-0 for definitions of these terms).

While intelligence has always been crucial for situational awareness and operational planning, the increased emphasis on problem framing and understanding the operational environment (including PMESII and DIME) may have implications for tools development since inputs from intelligence and situational awareness tools may form part of the operational planning process. Integration with intelligence analysis tools may be beneficial.

**Centre of Gravity – Decisive points**

Centre of Gravity (COG) and Decisive Points are important concepts to understand because COG analysis features prominently in our review of the literature related to operational planning tools. According to JP 5-0, a "COG is a source of power that provides moral or physical strength, freedom of action, or will to act" (p. xxi). There can be both friendly and adversary COGs. Friendly COGs need to be identified and protected while enemy COGs are "those aspects of the adversary's overall capability that, theoretically, if attacked and neutralized or destroyed will lead wither to the adversary's inevitable defeat or force opponents to abandon aims or change behavior" (Wade 2003, 5-2). COGs also form part of Canadian planning doctrine, however the CFOPP states that:

> Recent writings on the topic of centre of gravity have suggested that Western militaries have taken Clausewitz's concept of the Centre of Gravity too far. What was intended as an abstract analytical concept was never intended to be the singular focus of campaigning. As such, it has been suggested that the unifying focus of any campaign should be the evolving end state, goals and objectives and if a clear, useful centre of gravity is present then it should be included in the operational art (Chief of the Defence Staff 2008, 2-1).

Therefore the identification of COGs seems to be optional in the Canadian process. The CFOPP spends several paragraphs defining Decisive Points, which are defined as critical events that pave the way to the end state. The policy also specified that "analysis must also consider what the opposing force perceives as decisive points in relation to the end state, for these will indicate emphasis for force protection" (p. 2-1).

**Critical vulnerabilities (CV-CR)**

Critical vulnerabilities are often written about in the context of decisive points and COGs. The CFOPP states:

> While decisive points themselves are not necessarily vulnerable, a determination of *critical vulnerabilities* of each decisive point will reveal how it can best be achieved. For example, in determining how to achieve air superiority, analysis of aircrew, fuelling, aircraft capabilities, aircraft production, airfields, ground support and air defence, among others would reveal the most likely critical vulnerability for this decisive point (p. 2-2).

A recent article in *Joint Forces Quarterly* provides valuable insight into the importance of Centres of Gravity, Decisive Points, critical vulnerabilities and Critical Factors Analysis (CFA) (Rueschhoff and Dunne 2011). In this article, the authors speak of how the theories of Dr. Joe Strange on critical vulnerabilities and critical requirements (CV-CR) (Strange 1996; Strange and Iron 2001) have been widely adopted by militaries around the globe. However, they also believe that the theories have been applied incorrectly and that there needs to be a less linear approach to identifying COGs through an analysis of critical capabilities (CCs), critical requirements (CRs) and critical vulnerabilities (CVs). According to the authors, the US operational planning process does not specify an analytical process to assist with selecting COGs, so they propose a method of examining critical vulnerabilities and using a Critical Factors Analysis (CFA) approach. Strange and Iron put forward a method they coined the *CG-CC-CR-CV Construct* in 2001 (Strange and Iron 2001), which can be consulted for further details. In addition, twelve other articles in our dataset are related to critical vulnerabilities or critical factors analysis.

### 3.1.2 Major Research Topics

The literature search focused on publications discussing operational planning tools, which resulted in 325 bibliographic records of journal articles, conference papers, theses and dissertations as well as government technical reports and publications. A full description of the search strategy is provided in appendix 6.2. A list of all articles in the database, as well as all the publications cited in this report, is provided as an attachment.

A subject-based analysis of the keywords found in these bibliographic records allows us to identify the major research topics in this domain. Figure 1 below is a map of the major topics and the relationships between them. The lines between the nodes represent the strength of the correlation – the stronger the line, the stronger the correlation - and the size of the nodes represent the relative numbers of publications within each node. Some nodes have been manually coloured for emphasis (dark blue is the default colour).

Some points of interest in this graph are:

- Relatively high importance of effects-based concepts, as represented by the large size of the effects-based node (in yellow, containing 122 records, or 35% of the data);
- The importance of visualization, graphical interfaces, displays and conceptual graphs (coloured in light blue);
- High importance of simulation and modeling, represented by the very large size of their nodes, which are linked to games/wargaming as well as scenarios (red);
- The appearance of operational art concepts already discussed (green), such as CV-CR, COG and performance/effectiveness, a category that includes performance measures, metrics and measures of effectiveness.

Some analytical techniques are also shown in this graph (coloured in pink), such as:

- causal analysis
- system of systems analysis
- prediction and forecasting
- risk analysis
- coloured petri nets
- state space analysis.

Analytical methods are discussed in more detail in section 3.1.3 below.

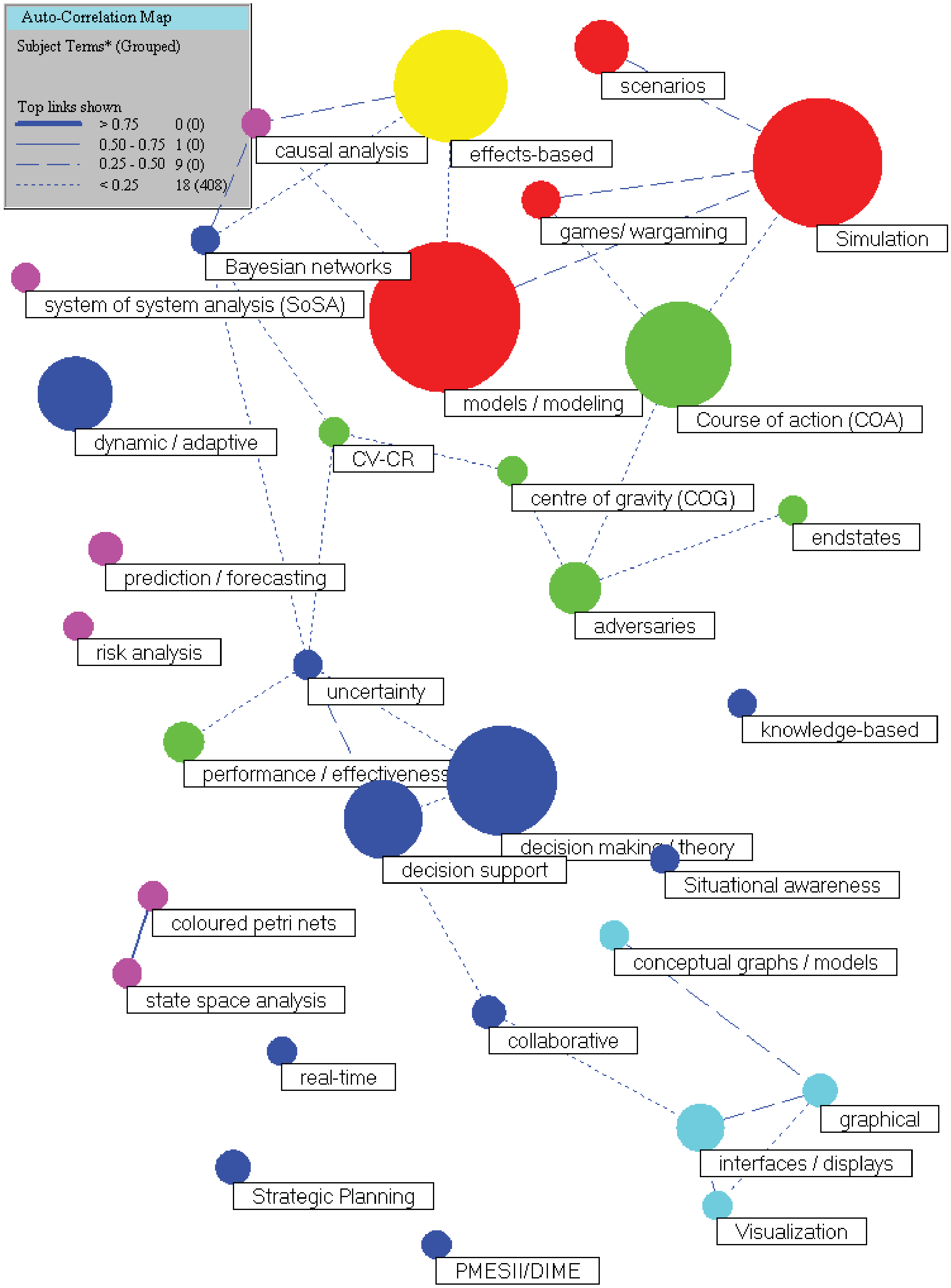

**Figure 1. Topic map – Operational Planning Tools Literature**

### 3.1.3 Analytical methods

The following summary of analytical methods is based upon a review of selected doctrinal documents and our analysis of papers related to operational planning tools development. There may be other analytical methods described in the literature, but our report is focused on those employed in operational planning tools.

Generally, it was found that in tools development, the operational planning aspect most supported is course of action analysis - usually involving scenario generation, war gaming or other simulations. Some element of risk analysis is also reported, as well as conceptual graphs or other graphical representations and decision aids such as scorecards for presenting and quantifying alternative courses of action.

Analysis topics found in our dataset included the following:

- Centre of Gravity (COG) analysis
- Course of Action (COA) analysis / assessment
- COA diagrams
- Risk analysis
- Scenario generation and scenario analysis
- Critical factors analysis (CFA) and critical path analysis
- Causal analysis (cause and effect)
- Systems of systems analysis (SoSA)
- Coloured Petri Nets
- Case-based reasoning
- Conceptual graphs
- State space analysis
- Behavioural analysis
- Link analysis
- Uncertainty analysis
- What-if analysis

To find articles in our dataset related to these subjects, the attachment to this report (filename: 7830 Operational Art 325 articles.xlsx), provides all references, with a field for subject terms that is searchable.

RAND Corporation provides a series of two papers on military planning and implications for tools development (Davis and Kahan 2007; Davis and Henninger 2007). In these papers, the authors argue for military planning systems (both strategic and operational) that are designed for dealing more effectively with uncertainty and risk and that account for different styles of decision making – a hybrid approach of traditional rational-analytic methods and a more naturalistic or intuitive approach which they call “creative critical review”. The tools they propose combine weighting different factors that could affect scenarios or courses of action, with activities such as exploratory analysis and human-gaming (red-teaming and foresight exercises) through careful scenario generation. Adaptive modeling methods are key to supporting their recommended approach. Agent-based models can be PMESII-sensitive and provide “modular multiresolution campaign models” or models that spin-off and develop separately small, specialized and readily modified models (Davis and Henninger 2007).

We saw earlier that modeling and simulation feature prominently in our dataset. If we add scenario generation and gaming/wargaming to that, the concept of modeling & simulation is covered in 68% of the papers in our dataset (223/325 papers). An analysis of different terminology under all of these categories resulted in the following types of models (we included types of scenarios in this categorization) featuring prominently (Table 1). We can see from this list that many of the simulations are of the battlefield or conflict scenarios, but we can also see some evidence of social and cultural modeling (PMESII group), and human behavioural modeling. In the methods section of the table we can see some of the associated technical methods such as stochastic models, discrete-event models, and predictive simulation.

**Table 1. Modeling and Simulation topics**

| Types of models / simulation | |
|---|---|
| | # records |
| Conflict/campaign modeling & sim | 31 |
| Effects-based modeling / simulation | 15 |
| Adversary modeling | 12 |
| COA modeling / simulation | 11 |
| Process models / simulation | 9 |
| PMESII models | 8 |
| Behavioural models | 6 |
| **Methods of modeling / simulation** | |
| | # records |
| Stochastic models | 9 |
| Coloured Petri Nets (CPN) | 8 |
| Conceptual models | 7 |
| Discrete event modeling / simulation | 7 |
| Monte Carlo simulation | 5 |
| Predictive simulation | 5 |
| Markov models | 4 |

## 3.2 Planning Outside the Military Domain

The identification of operational planning theories and concepts outside the military domain is somewhat problematic since the term "operational planning" can mean different things in different industries.

Initial searches in one database (Scopus) retrieved more than 100 articles related to planning, but after a review of the abstracts, only three areas seem to be closely related to military operational planning: space missions planning, strategic business planning, and software release planning. The characteristics of these domains that most closely match with military planning are that they are complex, work towards a pre-defined end state, involve a degree of risk analysis and typically test different scenarios or possible outcomes. The difference here between military operational planning and strategic business planning is that business planning is usually designed to determine what the appropriate end state will be (i.e. the business strategy), while military planning pre-defines the end state and develops a plan to meet that objective.

A complete review of the concepts related to strategic business planning is outside the scope of the present study; a few references to scenario generation tools that may have similar characteristics to military operational planning tools are provided below.

**IBM – Clarity 7** http://www.claritysystems.com/us/products/Clarity7/Pages/default.aspx
This is a full business planning suite of tools that includes budgeting, forecasting and analysis functions, such as scenario generation, modeling and scorecards. It is web and Excel-based.

**Scenario Generator – SG and SIMUL8** http://www.scenario-generator.com/index.php
This tool was developed for the National Health Service (NHS) in the UK. Simulation techniques model health and social care systems to enable planners, clinicians, analysts and managers to understand the most efficient and effective way of planning a service, taking into account variability and changes in demand and informing evidence-based decision-making. The tool supports strategic decision-making and the planning, commissioning and design of new models of care.

**VISUAL8 -** http://www.visual8.com/ is a Canadian company affiliated with Scenario Generator (above). They have completed many decision support projects for Canadian and US companies, primarily in health care and logistics.

## 3.3 Operational Planning Tools

Searches were conducted to identify military operational planning tools currently deployed or in development. In general, there is a lot of research taking place and several prototypes are described but it was difficult to identify which tools are actually deployed and being used by military planners. This is especially true of tools that are described as making use of effects-based planning. As previously mentioned, EBO was abandoned by the US military in 2008, but it is not clear what has happened to the tools that were developed making use of it.

An Excel spreadsheet is provided as an attachment to this report (filename: 7830 Operational Art tools & programs.xlxs), which provides further details on the planning tools described below.

### 3.3.1 DSTO and Defense Materiel Organization, Australia

**Course of Action Scheduling Tool (COAST)** - DSTO
This tool is based upon conceptual modeling of the planning domain (end states, conditions, available resources and limitations). COAST was presented at the 9th ICCRTS conference in 2004 (Zhang, Mitchell et al. 2004), and has been further described in papers up to 2008, but it's current status is not known. The system employs Coloured Petri Nets (CPNs) for modeling and analysis, which are also described in later papers (Kristensen, Mechlenborg et al. 2008; Mitchell, Kristensen et al. 2007).

**Course of Action Simulation (COA-Sim)** - DSTO
This is an earlier DSTO R&D program from 2003. It is an integrated modeling environment:

> …consisting of graphical user interfaces, intelligent agents, a constructive theatre-level simulation and an underlying architecture and concepts. Within this environment planners can construct, modify and analyse an entire operational-level course of action… Intelligent software agents in the COA-Sim environment support the planner using classical planning techniques which can find a set of alternative plans to achieve a given military end state, and analysing given plans to determine decision points (Burgess 2003, 1).

**Joint Planning Suite (JPS)** – Lockheed Martin, Defense Materiel Organization
The only recent reference to a planning tool from Australia that could be found was a reference to the Joint Planning Suite (JPS), under the Defense Materiel Organization project JP2030 Phase 8. Brief information on the project is found at this site:
http://www.defence.gov.au/dmo/esd/jp2030/jp2030ph8.cfm, which says that Lockheed Martin is the primary contractor for the tool, currently in development.

### 3.3.2 US Military projects

**COMPOEX (Conflict Modeling, Planning and Outcomes Experimentation)** – BAE Systems
Results of this DARPA research was originally published in 2007. Kott and Corpac write: "The Campaign Planning tool provides a framework to develop, visualize and manage the comprehensive campaign plan. Leaders can see the interconnections between different lines of effort, understand the impact of actions across the entire plan and assess and modify the plan based on measured performance on the ground" (Kott and Corpac 2007, 2). The tool is now being further developed by BAE and is being evaluated by The US Secretary of Defense, Cost Assessment and Program Evaluation (CAPE). Pete

Corpac (pcorpac@stassociates.com) and Lawrence Craig (craig.t.lawrence@baesystems.com), the BAE project manager for COMPOEX, can be contacted for further information.

**Commanders' Predictive Environment (CPE) project** – AFRL (with Northrop Grumman)
The objective of this project was to explore and develop capabilities to enable the Joint Force Air Component Commander (JFACC) to anticipate and shape the battle space, providing information that allows the JFACC and his staff to make better decisions. While this tool appears to be more tactical it may be interesting to monitor since in introduces behavioral models as a decision-making tool as well as PMESII dimensions (Miller 2008). The original solicitation for the project (https://www.fbo.gov/spg/USAF/AFMC/AFRLRRS/Reference-Number-BAA-06-07-IFKA/listing.html) included a section on defining and understanding the Operational Environment, and read as follows:

> To assist in understanding the operation environment, a System-of-Systems Analysis (SoSA) is employed, treating the battlespace as an interrelated system across Political, Military, Economic, Social, Information, and Infrastructure (PMESII) dimensions. This process attempts to:
>
> 1) Model and analyze adversaries, self, and neutrals as a complex adaptive system;
>
> 2) Understand key relationships, dependencies, and vulnerabilities of adversary/self/neutrals; and
>
> 3) Identify leverage points that represent opportunities to influence capabilities, perceptions, decision making, and behavior.
>
> The objective is to develop computer-based modeling and simulation capabilities that describe and project the complex dynamics of the operational environment (across PMESII dimensions) to better understand adversary/neutrals/self strengths, capabilities, vulnerabilities, and critical gaps. Technology needs include behavior models, model integration frameworks, and model development environments.

**Distributed Episodic Exploratory Planning (DEEP)** – research sponsored by DARPA and AFRL
This system is well described by Lachevet in his 2009 ICCRTS paper (Lachevet 2009) and the final technical report of the project in 2008 (Lachevet, Kaczynski et al. 2008). Lachevet writes: "One of the goals of this project was to develop a prototype system for distributed, mixed-initiative planning that improves decision-making by applying analogical reasoning over an experience base… The two key objectives of DEEP are:

- Provide a mixed-initiative planning environment where human expertise is captured and developed, then adapted and provided by a machine to augment human intuition and creativity
- Support distributed planners in multiple cooperating command centers to conduct distributed and collaborative planning" (Lachevet 2009, 4).

While the system appears to have been developed for tactical planning, the authors claim that case-based reasoning, and the object-oriented framework that supports the tool, the Core Plan

Representation (CPR), support multi-level planning at all levels (strategic, operational and tactical). In the system, both humans and machine entities provide information to the users that may steer them into the development of a better plan.

**Pre-conflict Management Tools (PCMT) -** National Defense University, Center for Technology and National Security Policy
Joint Forces Command (JFCOM) Joint Interagency Coordination Group (JIACG) served as the first test-bed for operational use and experimentation of PCMT. This description is taken from the abstract of the 2005 technical report on the program by Aaron Frank:

> The Pre-Conflict Management Tools (PCMT) Program was developed to transform how intelligence analysts, policy analysts, operational planners, and decision makers interact when confronting highly complex strategic problems. The PCMT Program capitalizes on technologies and methods that help users collect, process, perform analyses with large quantities of data, and employ computational modeling and simulation methods to determine the probability and likelihood of state failure. The Program's computational decision aids and planning methodology help policymakers and military planners devise activities that can mitigate the consequences of civil war, or prevent state failure altogether… The PCMT Program builds on social science research on state failure and conflict, by turning government users into consumers of social science models employed by academic researchers and validated through peer review processes and implementation by practitioners. By constructing an analytic suite out of existing models, the Program avoids the controversies of 1960's social science research programs, such as Project Camelot, by rejecting the notion of a single, government-sponsored theory of conflict or placing policymakers in the position of determining what is or is not valid social science (Frank 2005).

PCMT was intended to be a tool for many levels of planners, including policy analysts, policy makers and operational planners; it seems to apply more for strategic than operational level planning but is interesting in that it inserts social science models into a planning system and considers the PMESII dimensions. PCMT is divided into three subsystems: data collection, analytic modeling and simulation, and interagency collaboration infrastructure. The modeling and simulation subsystem makes use of a Computer Assisted Reasoning System (CARS) to model multiple parameters of social vulnerability models, sometimes concurrently. This allows for the outputs of different models to be compared and identifies the divergence and convergence of expectations across competing scenarios or multiple users (Frank 2005).

**Course of Action Simulation Analysis (CASA) –** AFRL with SAIC
This project is described by Hanna, Reaper et al., who discuss the effect that the EBO process had on tools development, particularly in that functionality had to be developed for testing and simulating multiple courses of action and generating different scenarios for different centres of gravity (Hanna, Reaper et al. 2005). At the time of writing, the authors stated that techniques were "being investigated to quantitatively and methodically compare EBO-based COAs based on a common scoring system". The

scorecard tool they adopted was DynaRank, by the RAND Corporation, upon which they based the development of JavaRank, a tool with all the same features as DynaRank, but on a Java platform. DynaRank provides a scorecard system that shows assessment of each option's likely values in different columns and colours, and is based upon a multi-criteria decision analysis model. The authors also suggest that there may be other ways of computing the COA scores, such as a Bayesian belief network – which JavaRank could support. The current status of the CASA project is not known, nor is it known to what extent the tools specifically designed to support the EBO process are still being used.

**JavaRank decision support tool** – SAIC
JavaRank is based on the DynaRank tool (described below). It supports course of action analysis (Cox and Reaper 2005).

**DynaRank** – RAND Corporation
Developed by RAND in 1998, DynaRank is a decision support system that allows detailed high-level evaluation of policy options. While the tool is somewhat old, it is reported here because it was developed specifically for the military and it has formed the basis for further refinement and tools development, such as JavaRank described above. Further information can be found from the RAND publication *Resource Allocation for the New Defense Strategy: The DynaRank Decision-Support System* (Hillestad and Davis 1998).

**GCCS-J Joint Operation Planning and Execution System (JOPES)**
The Global Command and Control System (GCCS) is a process and suite of tools for US military planning. The JOPES subsystem is specifically designed for joint planning. Descriptions of the tools could not be located, probably because they are classified, but a 2010 request for information (RFI) was issued by the Defense Information Systems Agency (DISA) for future development of GCCS-J, and in particular JOPES (https://www.fbo.gov/?s=opportunity&mode=form&id=1414343ae44406ccf9936f40c9331894):

> A key portion of the GCCS-J functional capabilities are the force planning products commonly referred to as the Joint Operational Planning and Execution System (JOPES). It is the functionality encompassed in these products, which provides the Joint Staff and Unified commands their primary conventional war planning tools and capabilities."

This solicitation seems to imply that there will be developments and modifications to the JOPES software in the near future, but more specific information could not be found. Some information on the functionalities of JOPES can be gleaned from this website:
http://www.almc.army.mil/alog/issues/mayjun04/alog_joint_force.htm

### 3.3.3 NATO TOPFAS

TOPFAS (Tools for Operations Planning Functional Area Services) is an integrated set of tools to support system analysis, operations planning, execution, and assessment of operational campaigns. The

Operational Planning tool (OPT) is a campaign planning tool that provides causal, geo-spatial, temporal and resource views. Multiple strategic options and operational courses of actions can be developed and synchronized in space and time. Multi-actor perspectives can be represented in the same plan. The tool incorporates effects-based planning and can create series of courses of action for comparison, according to what is required from NATO's *Comprehensive Operational Planning Directive (COPD).* The tool is described in detail a 2001 ICCRTS paper (Thuve 2001) but more recent information is available from NATO (Tamai 2010).

### 3.3.4 NASA

**EUROPA (Extensible Universal Remote Operations Planning Architecture)**
This tool was released as Open-Source software in 2008 (http://ti.arc.nasa.gov/tech/asr/planning-and-scheduling/). It is a framework to tackle problems in planning, scheduling and constraint programming. The EUROPA wiki provides more information for developers: http://code.google.com/p/europa-pso/.

**NASA Next Generation Planning System (NGPS)**
This description is copied directly from NASA's website (http://ti.arc.nasa.gov/tech/asr/planning-and-scheduling/):

> The Next Generation Planning System (NGPS) is a suite of planning tools being developed as acollaboration between Johnson Space Center (JSC), Ames Research Center (ARC), the Jet Propulsion Laboratory (JPL) which will address planning needs for both ISS and future Mission Operations Directive (MOD) missions. Score is the planning interface to be used by NASA, the European Space Agency (ESA), and the Japan Aerospace Exploration Agency (JAXA) for authoring the operations schedule and validating it against flight rules and constraints. Score also provides an interface for planning collaboration between remote planners as well as a plugin-based architecture for partners from Marshall Space and Flight Center (MSFC), ESA, and JAXA to contribute their own custom tools.

Further information on Score and the tools developed by ESA could not be found, but according to a Spring 2011 NASA newsletter, the NGPS was almost ready to be deployed at that time (www.jsc.nasa.gov/roundup/online/2011/0311.pdf ). Some technical details about EUROPA and NGPS can be found in two conference papers (Frank, Morris et al. 2008; Smith and Korsmeyer 2010).

## 3.4 Patent Results

A series of patent searches were conducted to identify operational planning tools in the military domain, or similar tools from outside the field. Our results were limited, primarily because software is not protected by patent laws in all countries and so there is a distinct lack of software patents available. Software can be patented in the US and a few other countries if it is related to hardware or a specific business process, so there are some results of interest. The following table lists the patents that appear to be closest to the client's area of interest. Copies of patents may be obtained by searching on the patent numbers at the European Patent Office site EspaceNet: http://worldwide.espacenet.com/ or the US Patent and Trademark Office: http://patft.uspto.gov/.

**Table 2. Patent results**

| Patent Number | Title | Inventor(s) | Patent Assignee(s) |
|---|---|---|---|
| EP1595221 | CASCADED PLANNING OF AN ENTERPRISE PLANNING MODEL | THIER ADAM | ADAYTUM;<br>IBM |
| EP1595204 | HORIZONTAL ENTERPRISE PLANNING IN ACCORDANCE WITH AN ENTERPRISE PLANNING MODEL | THIER ADAM | ADAYTUM;<br>IBM |
| WO200273860 | SYSTEM AND METHOD FOR MODELING AND ANALYZING STRATEGIC BUSINESS DECISIONS | ADLER RICHARD M | ADLER RICHARD M |
| WO200508404 | MODELING OF APPLICATIONS AND BUSINESS PROCESS SERVICES THROUGH AUTO DISCOVERY ANALYSIS | WONG WAI; YOUNG ALAN | COMPUTER ASSOCIATES THINK |
| US20030033302 | Method for collective decision-making | BANERJEE DWIP N; DUTTA RABINDRANATH | IBM |
| EP0601949 | Conceptual map showing the windows of a complex task. | KING DAVID C; TORRES ROBERT J | IBM |
| WO200468318 | CULTURAL SIMULATION MODEL FOR MODELING OF AGENT BEHAVIORAL EXPRESSION AND SIMULATION DATA VISUALIZATION METHODS | FABLES WYLCI; PARK JORE; COLT JONATHAN | INDASEA INC;<br>SEASEER RESEARCH & DEVELOPMENT |
| US20060190420 | Interactive course of action analysis tool | TALBOT PATRICK J | NORTHROP GRUMMAN |
| US20100042418 | TECHNICAL TOOLS FOR COMPLEX INFORMATION | OLSSON KJELL | OLSSON KJELL |
| US20110087515 | Cognitive interactive mission planning system and method | MILLER BRADFORD W; HWANG CHUNG H | RAYTHEON |

## 3.5 Major Players

All data presented in this section are based upon our search of operational planning tools and so do not represent experts in operational planning per se, but rather on the tools development side.

### 3.5.1 International organizations

Figure 2 below shows all organizations with six (6) or more publications in our dataset. Other organizations in the dataset, but not found in these graphs are: RAND Corporation (5 publications), Lockheed Martin Corp (4), NATO (4), National University of Defense Technology, China (4), US Air Force Institute of Technology (3) and many others, mostly American defence organizations and large universities.

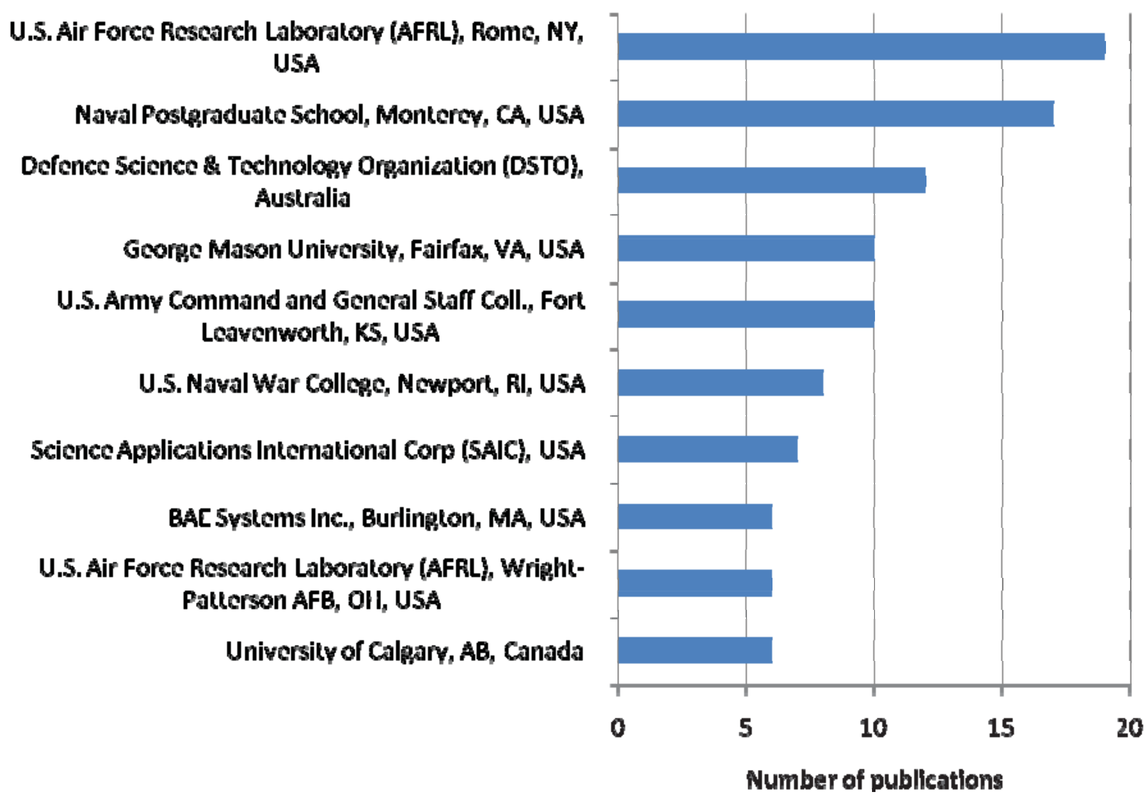


**Figure 2. Top Organizations – Numbers of Publications**

Figure 3 (below) illustrates the areas of expertise of the top organizations, by broad subject classifications.

Subject Groups

| Name | analysis methods | collaborative | decision support | dynamic/ adaptive | effects-based | interfaces/ visualization | knowledge based | modeling & simulation | operational art/ planning | performance/ effectiveness | prediction/ forecasting |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AFRL, Rome, NY, USA | 2 | | 12 | 9 | 14 | 2 | 1 | 18 | 17 | 5 | 5 |
| AFRL, Wright-Patterson AFB, OH, USA | | 1 | 4 | 2 | 2 | 4 | 1 | 5 | 4 | 1 | 2 |
| BAE Systems Inc., USA | 2 | 4 | 2 | 1 | 5 | 2 | 1 | 6 | 4 | | 1 |
| DSTO, Australia | 4 | 1 | 6 | 2 | 4 | 2 | 2 | 10 | 7 | 2 | |
| George Mason University, VA, USA | 6 | 2 | 4 | 3 | 7 | 4 | 3 | 7 | 8 | 2 | |
| Naval Postgraduate School, Monterey, CA, USA | 1 | 2 | 8 | 2 | 5 | 5 | | 15 | 5 | 2 | 2 |
| SAIC, USA | 1 | 3 | 5 | 2 | 6 | 4 | | 6 | 5 | 2 | 1 |
| University of Calgary, AB, Canada | 3 | | 4 | 3 | | | | 6 | 5 | 1 | |
| US Army Command and General Staff Coll., KS, USA | 4 | | 5 | 2 | 1 | 2 | | 6 | 5 | 1 | |
| US Naval War College, Newport, RI, USA | 1 | 1 | 4 | 1 | 4 | | | 5 | 6 | 1 | 1 |

**Figure 3. Top Organizations – Areas of Expertise – Numbers of Publications**

### 3.5.2 Canadian organizations

There are 25 publications in the dataset authored by Canadians affiliated with 15 different organizations. The University of Calgary stands out because of the six publications in our dataset on software release planning, most authored by Ahmed Al-Emran (http://people.ucalgary.ca/~aalemran/).

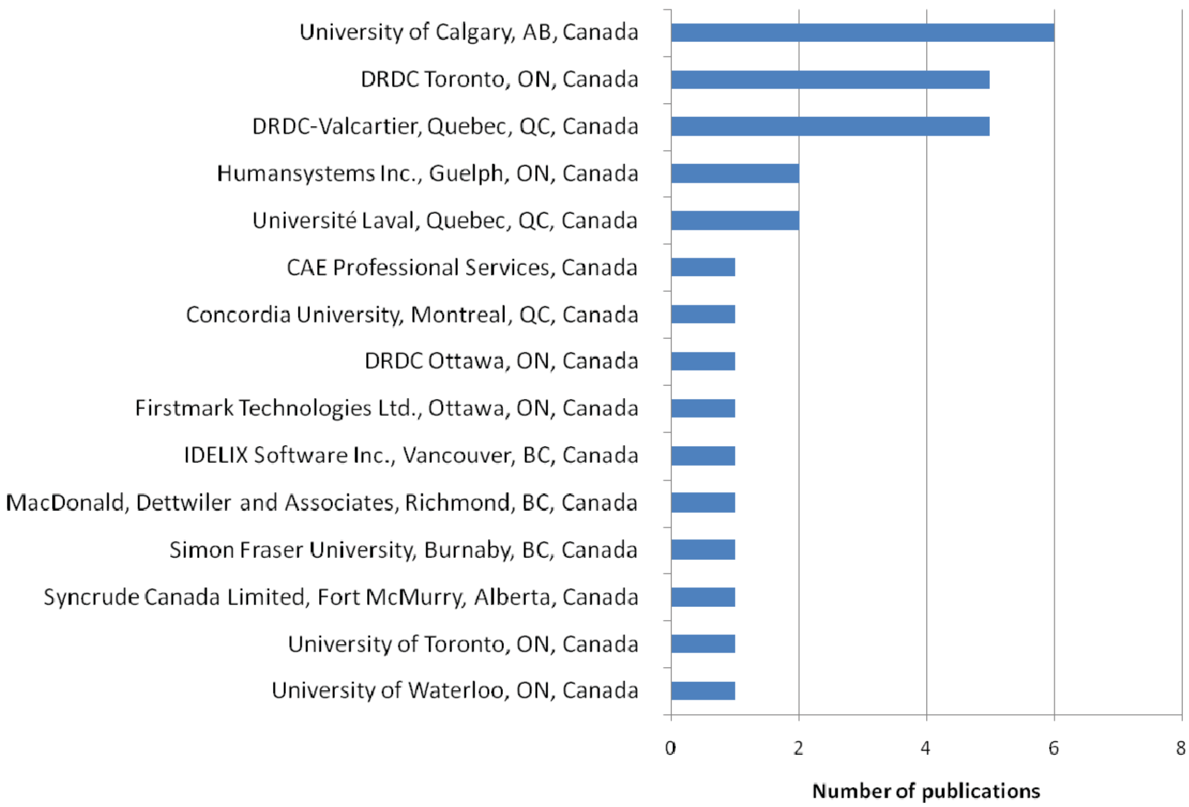


**Figure 4. Canadian Organizations, Numbers of publications**

# 3.6 Leading Experts

## 3.6.1 International Experts

Table 3 lists the leading experts, based on numbers of publications in our dataset. Most of these hail from those organizations that were also found in our top 10 or top 15 major players' lists.

**Table 3. Top Experts by Numbers of Publications, International**

| Author Name | # of Publications |
|---|---|
| Gilmour, D. A.;<br>U.S. Air Force Research Laboratory (AFRL), Rome, NY, USA | 10 |
| Levis, A. H.;<br>George Mason University, Fairfax, VA, USA | 7 |
| Pioch, N. J.;<br>BAE Systems Inc., Burlington, MA, USA | 7 |
| Wagenhals, L. W.;<br>George Mason University, Fairfax, VA, USA | 7 |
| Cohen, P. R.;<br>University of Massachusetts, Amherst, MA, USA | 5 |
| Forbus, K. D.;<br>Northwestern University, Evanston, IL, United States | 5 |
| Hanna, J. P.;<br>U.S. Air Force Research Laboratory (AFRL), Rome, NY, USA | 5 |
| Zhang, Lin;<br>Defence Science & Technology Organization (DSTO), Australia | 5 |

### 3.6.2 Canadian Experts

Table 4 lists the leading authors from Canadian institutions. More details on their co-authors and areas of expertise are provided in appendix 6.5. There are considerably less Canadian authors in our dataset and so a listing of top authors is somewhat misleading. In the table below, we list instead groups of authors from the top institutions in Canada – numbers in square brackets show the number of publications in our dataset for that author.

**Table 4. Leading Canadian Authors**

| Author Name(s) | Affiliation of Author | # of publications collectively |
|---|---|---|
| Al-Emran, A.[5]<br>Pfahl, D.[5]<br>Ruhe, G.[4] | University of Calgary, AB, Canada [5]; | 5 |
| Belanger, Micheline[3];<br>Guitouni, Adel[2];<br>Boukhtouta, A.[2] | DRDC-Valcartier, Quebec, QC, Canada [3]; | 3 |
| Lamoureux, T. M.[3];<br>Rehak, L. A.[3] | Humansystems Inc., Guelph, ON, Canada [2];<br>DRDC Toronto, ON, Canada [1] | 3 |
| Bruyn Martin L.[2];<br>Bryant, D. J.[2] | DRDC Toronto, ON, Canada [1]; | 2 |
| Moulin, B.[2] | Université Laval, Quebec, QC, Canada [2]; | 2 |

# 4 CONCLUSIONS

**Issues and limitations**

This study provides a very basic discussion of operational art theories and methods to highlight some of the trends that may affect operational planning tools development. Readers with more knowledge in operational art may benefit from a closer review of the sources cited in this report.

Despite several iterative literature searches, it was a challenge to identify parallels to operational planning in other industries. Many of the results retrieved were only marginally relevant to this study and so the strategy was to retain primarily those articles specifically related to military operational planning tools. The resulting dataset contained 325 very relevant publications; however this is a relatively small dataset for investigating research trends through bibliometric analysis. The methods for this study therefore combined a small measure of bibliometric analysis to discern major topics, with a literature review of reading and commenting on selected articles.

**Areas for further study**

While the Canadian Forces have not yet adopted concepts of effects-based operations or operational design into doctrine, it is clear that these concepts are influencing doctrine in other countries and the development of associated tools. Elements that may influence tools development and that should be monitored for new developments are the following:

- Tools should facilitate creativity and non-linear planning approaches, allowing more space for humans-in-the-loop;
- Planning processes may place more emphasis on framing the problem, causal analysis and on iterations in problem development where choosing a course of action may be the best way of identifying other aspects of the problem;
- Tools should be adaptive and provide for modeling and simulation of multiple scenarios or courses of action;
- Tools should employ multiple models and agents that introduce elements of PMESII (social science models), as well as including non-military instruments (DIME) in the courses of action;
- The identification of centres of gravity and decisive points remain important in all doctrine, but there should be emphasis on critical factors analysis through the CV-CR construct.

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# 6 APPENDICES

## 6.1 Attachments

The following documents are provided as attachments to this report:

| Filename | Description |
|---|---|
| 7830 Operational Art tools & programs.xlsx | Details on operational planning tools |
| 7830 Operational Art 325 articles.xlsx | Scientific publications analysed for this report. |
| 7830 Operational Art patents.xlsx | Patent results |

## 6.2 Methodology

### 6.2.1 Searches

Several searches were conducted in various databases, particularly *INSPEC, Ei-Compendex, Scopus*, *NTIS* and *NATO Scientific Publications*. Results were limited to the last 10 years.

Conference proceedings of the annual International Command and Control Research and Technology Symposium (2001-2011) were scanned for relevant articles and manually added to the database.

The table below shows groups of concepts, which were combined in multiple variations using database-specific syntax to obtain relevant references.

**Search concepts:**

| 1: Operational planning | 2: Tools | 3: Military domain |
|---|---|---|
| Operation* plan*<br>Campaign plan*<br>Operational art<br>____________________<br>Course of action<br>Center of gravity<br>Critical vulnerabilit*<br>Decisive point*<br>Military end state<br>Effects based operations<br>Critical (path or capabilit* or requirement)<br>Risk (analysis or identif* or manage* or assess*)<br>Conceptual graphs or CG theory | Tools<br>Software<br>Computer programs<br>Interface*<br>GUI<br>Decision aids<br>____________________<br>Simulation<br>Models | Military<br>Armed forces<br>Army<br>Navy<br>Air Force<br>Battlespace<br>Joint forces<br>Peacekeeping<br>MOOTW<br>Disaster relief<br>Humanitarian assistance<br>Counterinsurgency<br>Joint military activity |

The search combined these sets in several variations and some strings were limited to title, subject heading or keywords for greater precision. All results were limited to 2001-2011. Abstracts were manually scanned and weeded, resulting in a dataset of 319 records.

A similar search strategy was applied in the FamPat worldwide patents database from Questel-Orbit, however there were very few references that were deemed relevant.

### 6.2.2 Analysis

All references were downloaded into VantagePoint software for analysis. VantagePoint allows us to create various groupings, matrices, graphs, cross-correlations and statistical analyses to analyze the data and draw conclusions about topics and subtopics and to profile the activities of the major players.

Author names and author affiliations were cleaned to harmonize variant forms and spellings and group together departments from the same institutions.

Keywords, identifiers (akin to author-supplied keywords), descriptors, subject headings and phrases and words from titles and abstracts were merged together to facilitate subject analysis, resulting in over 9,000 terms. These terms were cleaned and edited to harmonize variant spellings, acronyms and similar meanings. These terms were then grouped into thematic categories for further analysis and discussion.

### 6.2.3 Sources Consulted

**Scientific & Technical Literature databases**:

- *Scopus* (accessed via CISTI license)
- *INSPEC* (accessed via CISTI license)
- *EiCompendex* (accessed via CISTI license)
- *NTIS* (accessed via Dialog online search service)
- DTIC Online – *Technical Publications* http://www.dtic.mil/dtic/search/tr/tr.html
- NATO Research & Technology Organisation - *Scientific Publications* http://www.rta.nato.int/abstracts.aspx
- DSTO *Publications Online* http://dspace.dsto.defence.gov.au/dspace/

**Market and Trade Literature**:

- Frost & Sullivan (accessed via CISTI license)

**Other Sources :**

- Command and Control Research Program (CCRP) website http://www.dodccrp.org/

## 6.3 Recommended Sources

In addition to the references provided in section 5, the following resources are recommended for further information.

**Military Operational Planning Doctrine**

Australian Defence Force. 2007. *Joint Operations for the 21st Century.* Canberra: ADF. http://www.defence.gov.au/publications/FJOC.pdf

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**Other Sources:**

US Air University. Behavioral Influences Analysis Center. *Analysis & assessment modeling and simulation tools* [web page] http://www.au.af.mil/bia/tools.htm. This site provides links to modeling and simulation tools from AFRL and associated partners.

## 6.4 Major Players Data

**Table 5. Top 15 organizations by numbers of publications**

| Organization Name | Top Authors | Co-Authoring Institutions | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| U.S. Air Force Research Laboratory (AFRL), Rome, NY, USA[19] | Gilmour, D. A. [10];<br>Hanna, J. P. [4];<br>McKeever, W. E. [4];<br>Krause, L. S. [3];<br>Lehman, L. A. [3];<br>McKeever, J. W. [3];<br>Walter, M. J. [3] | RAM Laboratories, Inc., San Diego, CA [1] | Simulation [16];<br>Course of action (COA) [14];<br>effects-based [14];<br>decision making / theory [11];<br>adversaries [10];<br>games/ wargaming [10];<br>models / modeling [10];<br>dynamic / adaptive [9];<br>scenarios [9];<br>centre of gravity (COG) [6]; | 2002 - 2009 |
| Naval Postgraduate School, Monterey, CA, USA[17] | Hutchins, S. G. [3];<br>Kemple, W. G. [3];<br>Kleinman, D. L. [2];<br>Miller, S. [2] | | models / modeling [11];<br>scenarios [10];<br>Simulation [10];<br>decision support [7];<br>effects-based [5];<br>decision making / theory [4];<br>games/ wargaming [4];<br>Course of action (COA) [3];<br>graphical [3];<br>interfaces / displays [3]; | 2001 - 2011 |

| Organization Name | Top Authors | Co-Authoring Institutions | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| Defence Science & Technology Organization (DSTO), Australia[12] | Zhang, Lin [4];<br>Kristensen, Lars M. [3];<br>Mitchell, Brice [3];<br>Falzon, L. [2] | Australian National University, Canberra, ACT, Australia [1];<br>National ICT Australia, Canberra, Australia [1] | models / modeling [6];<br>Simulation [6];<br>decision making / theory [4];<br>effects-based [4];<br>Course of action (COA) [3];<br>decision support [3];<br>adversaries [2];<br>causal analysis [2];<br>centre of gravity (COG) [2];<br>coloured petri nets [2];<br>CV-CR [2];<br>dynamic / adaptive [2];<br>endstates [2];<br>knowledge-based [2];<br>performance / effectiveness [2];<br>scenarios [2];<br>state space analysis [2] | 2003 - 2009 |
| George Mason University, Fairfax, VA, USA[10] | Levis, A. H. [6];<br>Wagenhals, L. W. [5];<br>Haider, S. [3];<br>Boicu, C. [2];<br>Boicu, M. [2];<br>Comello, J. [2];<br>Marcu, D. [2];<br>Stanescu, B. [2];<br>Tecuci, G. [2];<br>Zaidi, A.K. [2] | Institute of Business Administration, Karachi, Pakistan [1] | Course of action (COA) [8];<br>effects-based [7];<br>models / modeling [7];<br>Bayesian networks [4];<br>coloured petri nets [4];<br>causal analysis [3];<br>dynamic / adaptive [3];<br>games/ wargaming [3];<br>graphical [3];<br>knowledge-based [3] | 2001 - 2008 |

| Organization Name | Top Authors | Co-Authoring Institutions | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| U.S. Army Command and General Staff Coll., Fort Leavenworth, KS, USA[10] | Allen, J. C. [1];<br>Donlon, J. J. [1];<br>Gregor, William J. [1];<br>Groen, Jelte R. [1];<br>Leavitt, W. [1];<br>Madera, J. M. [1];<br>Marr, J. J. [1] | | decision making / theory [4];<br>models / modeling [4];<br>system of system analysis (SoSA) [3];<br>adversaries [2];<br>Course of action (COA) [2];<br>dynamic / adaptive [2];<br>scenarios [2];<br>Simulation [2];<br>causal analysis [1];<br>centre of gravity (COG) [1];<br>decision support [1];<br>effects-based [1];<br>interfaces / displays [1];<br>performance / effectiveness [1];<br>PMESII/DIME [1] | 2001 - 2011 |
| U.S. Naval War College, Newport, RI, USA[8] | Canon, C. H. [1];<br>Christie, J. L. [1];<br>Dees, D. S. [1];<br>DeLange, E. P. [1];<br>Hannan, M. J. [1];<br>Linkous, F. S. [1];<br>McRae, K. D. [1] | | adversaries [5];<br>models / modeling [5];<br>effects-based [4];<br>decision support [3];<br>decision making / theory [2];<br>PMESII/DIME [2];<br>Simulation [2];<br>centre of gravity (COG) [1];<br>collaborative [1];<br>Course of action (COA) [1];<br>CV-CR [1];<br>dynamic / adaptive [1];<br>endstates [1];<br>performance / effectiveness [1];<br>prediction / forecasting [1];<br>real-time [1];<br>system of system analysis (SoSA) [1] | 2003 - 2009 |

| Organization Name | Top Authors | Co-Authoring Institutions | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| Science Applications International Corp (SAIC), USA[7] | Reaper, J. [3];<br>Cox, T. [2] | | effects-based [6];<br>models / modeling [6];<br>Simulation [6];<br>Course of action (COA) [4];<br>adversaries [3];<br>collaborative [3];<br>decision making / theory [3];<br>decision support [3];<br>Visualization [3];<br>dynamic / adaptive [2];<br>performance / effectiveness [2] | 2001 - 2007 |
| BAE Systems Inc., Burlington, MA, USA[6] | Pioch, N. J. [4];<br>White, C. M. [2] | | effects-based [5];<br>models / modeling [5];<br>collaborative [4];<br>adversaries [3];<br>real-time [3];<br>centre of gravity (COG) [2];<br>endstates [2];<br>games/ wargaming [2];<br>interfaces / displays [2];<br>Simulation [2] | 2005 - 2008 |
| U.S. Air Force Research Laboratory (AFRL), Wright-Patterson AFB, OH, USA[6] | Aleva, D. [1];<br>Busch T. E. [1];<br>Caffrey, J. M. [1];<br>Dixon, S. [1];<br>Fitzhugh, E. [1];<br>Garrambone, M. W. [1];<br>Jacobs, T. H. [1] | General Dynamics, Dayton, OH, USA [1];<br>Northrop Grumman Corp., USA [1];<br>SRA International, Inc., Dayton, OH, United States [1];<br>U.S. Air Force Institute of Technology (AFIT), Wright-Patterson AFB, OH, USA [1] | Simulation [5];<br>Course of action (COA) [4];<br>decision making / theory [3];<br>models / modeling [3];<br>adversaries [2];<br>decision support [2];<br>dynamic / adaptive [2];<br>effects-based [2];<br>interfaces / displays [2];<br>prediction / forecasting [2]; | 2002 - 2009 |

| Organization Name | Top Authors | Co-Authoring Institutions | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| University of Calgary, AB, Canada[6] | Al-Emran, A. [5];<br>Pfahl, D. [5];<br>Ruhe, G. [3] | City University of Hong Kong, Kowloon, Hong Kong [1];<br>Northeastern University, Shenyang, China [1];<br>Simula Research Laboratory, Lysaker, Norway [1];<br>University of Oslo, Norway [1] | Simulation [5];<br>Strategic Planning [5];<br>scenarios [4];<br>decision making / theory [3];<br>dynamic / adaptive [3];<br>models / modeling [3];<br>decision support [2];<br>risk analysis [2];<br>CV-CR [1];<br>performance / effectiveness [1];<br>system of system analysis (SoSA) [1] | 2003 - 2010 |
| DRDC Toronto, ON, Canada[5] | Bryant, D. J. [2] | DRDC-Valcartier, Quebec, QC, Canada [1] | decision making / theory [3];<br>models / modeling [3];<br>conceptual graphs / models [2];<br>collaborative [1];<br>decision support [1];<br>dynamic / adaptive [1];<br>graphical [1];<br>real-time [1] | 2004 - 2009 |
| DRDC-Valcartier, Quebec, QC, Canada[5] | Belanger, Micheline [3];<br>Boukhtouta, A. [2];<br>Guitouni, Adel [2] | Concordia University, Montreal, QC, Canada [1];<br>DRDC Toronto, ON, Canada [1];<br>MacDonald, Dettwiler and Associates (MDA), Richmond, BC, Canada [1];<br>Université Laval, Quebec, QC, Canada [1] | decision making / theory [3];<br>Course of action (COA) [2];<br>decision support [2];<br>dynamic / adaptive [2];<br>centre of gravity (COG) [1];<br>conceptual graphs / models [1];<br>effects-based [1];<br>knowledge-based [1];<br>models / modeling [1];<br>real-time [1];<br>risk analysis [1];<br>uncertainty [1] | 2002 - 2011 |

| Organization Name | Top Authors | Co-Authoring Institutions | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| RAND Corp., Santa Monica, CA, USA[5] | Davis, P. K. [4];<br>Kahan, J. P. [3] | | effects-based [4];<br>decision making / theory [3];<br>models / modeling [3];<br>risk analysis [3];<br>uncertainty [3];<br>decision support [2];<br>dynamic / adaptive [2];<br>PMESII/DIME [2];<br>prediction / forecasting [2];<br>Simulation [2]; | 2001 - 2007 |
| Swedish Defence Research Agency (FOI), Stockholm, Sweden[5] | Moradi, F. [3];<br>Schubert, J. [3] | Royal Institute of Technology (KTH), Stockholm, Sweden [1] | Simulation [4];<br>decision making / theory [3];<br>effects-based [3];<br>endstates [3];<br>Course of action (COA) [2];<br>decision support [2];<br>models / modeling [2];<br>scenarios [2];<br>Situational awareness [2];<br>dynamic / adaptive [1];<br>games/ wargaming [1];<br>knowledge-based [1] | 2001 - 2010 |

## 6.5 Leading Experts Data

**Table 6. Leading Experts - International**

| Author Name | Affiliation of Author | Co-Authors | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| Gilmour, D. A.[10] | U.S. Air Force Research Laboratory (AFRL), Rome, NY, USA [10] | Hanna, J. P. [4];<br>McKeever, W. E. [4];<br>McKeever, J. W. [3];<br>Walter, M. J. [3] | Simulation [10];<br>Course of action (COA) [9];<br>decision making / theory [9];<br>adversaries [8];<br>effects-based [8];<br>scenarios [8];<br>dynamic / adaptive [6];<br>games/ wargaming [6] | 2004 - 2008 |
| Levis, A. H.[7] | George Mason University, Fairfax, VA, USA [6]; | Wagenhals, L. W. [4];<br>Haider, S. [3];<br>McCrabb, M. [1];<br>Zaidi, A.K. [1] | effects-based [7];<br>models / modeling [7];<br>Course of action (COA) [6];<br>Bayesian networks [5];<br>causal analysis [3];<br>coloured petri nets [3];<br>decision making / theory [2];<br>dynamic / adaptive [2];<br>games/ wargaming [2];<br>graphical [2];<br>interfaces / displays [2];<br>performance / effectiveness [2] | 2001 - 2008 |
| Pioch, N. J.[7] | BAE Systems Inc., Burlington, MA, USA [4];<br>ALPHATECH Inc., Burlington, MA USA [2]; | White, C. M. [4];<br>Graham, S. [2];<br>Jones, E. K. [2];<br>Prendergast, M. [2] | effects-based [7];<br>models / modeling [5];<br>adversaries [4];<br>collaborative [4];<br>causal analysis [3];<br>centre of gravity (COG) [3];<br>interfaces / displays [3]; | 2002 - 2006 |

| Author Name | Affiliation of Author | Co-Authors | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| Wagenhals, L. W.[7] | George Mason University, Fairfax, VA, USA [5]; | Levis, A. H. [4];<br>DeGregorio, E. A. [1];<br>Haider, S. [1];<br>Janssen, R. A. [1] | Course of action (COA) [6];<br>effects-based [6];<br>models / modeling [6];<br>coloured petri nets [4];<br>Bayesian networks [3];<br>games/ wargaming [3];<br>graphical [3];<br>interfaces / displays [3];<br>performance / effectiveness [3] | 2001 - 2007 |
| Cohen, P. R.[5] | University of Massachusetts, Amherst, MA, United States [4];<br>Texas Univ., Austin, TX USA [1] | King, G. [2];<br>Westbrook, D. L. [2];<br>Atkin, M. [1];<br>Barker K [1] | Simulation [5];<br>Course of action (COA) [4];<br>dynamic / adaptive [4];<br>games/ wargaming [3];<br>effects-based [2];<br>graphical [2];<br>knowledge-based [2] | 2002 - 2005 |
| Forbus, K. D.[5] | Northwestern University, Evanston, IL, United States [2];<br>Battle Command Battle Lab, Ft. Leavenworth, KS, United States [1];<br>BBN Technologies, USA [1];<br>Texas Univ., Austin, TX USA [1] | Usher, J. [3];<br>Chapman, V. [2];<br>Kott, A. [2];<br>Rasch, R. [2] | Course of action (COA) [5];<br>graphical [4];<br>conceptual graphs / models [3];<br>interfaces / displays [3];<br>adversaries [2];<br>decision making / theory [2];<br>knowledge-based [2]; | 2002 - 2003 |
| Hanna, J. P.[5] | U.S. Air Force Research Laboratory (AFRL), Rome, NY, USA [4];<br>Science Applications International Corp (SAIC), USA [1] | Gilmour, D. A. [4];<br>Walter, M. J. [4];<br>McKeever, J. W. [2];<br>Blank, G. [1] | adversaries [5];<br>Course of action (COA) [5];<br>Simulation [5];<br>decision making / theory [4];<br>effects-based [4];<br>models / modeling [4];<br>decision support [3];<br>games/ wargaming [3];<br>performance / effectiveness [3];<br>real-time [3] | 2004 - 2006 |

| Author Name | Affiliation of Author | Co-Authors | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| Zhang, Lin[5] | Defence Science & Technology Organization (DSTO), Australia [4];<br>Australian National University, Canberra, ACT, Australia [1];<br>National ICT Australia, Canberra, Australia [1];<br>Univ. of Aarhus, Denmark [1] | Zhang, Lin [5];<br>Kristensen, Lars M. [4];<br>Mitchell, Brice [4];<br>Gallasch, Guy [2];<br>Mechlenborg, Peter [2] | coloured petri nets [3];<br>models / modeling [3];<br>state space analysis [3];<br>Course of action (COA) [2];<br>performance / effectiveness [2];<br>Simulation [2];<br>decision making / theory [1];<br>decision support [1];<br>dynamic / adaptive [1];<br>effects-based [1];<br>graphical [1];<br>interfaces / displays [1] | 2004 - 2008 |

**Table 7. Leading Canadian Experts**

| Author Name(s) | Affiliation of Author | Co-Authors | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| Al-Emran, A.[5]<br>Pfahl, D.[5]<br>Ruhe, G.[4] | University of Calgary, AB, Canada [5]; | Al-Emran, A. [5];<br>Pfahl, D. [5];<br>Ruhe, G. [3];<br>Momoh, J. [1] | Simulation [5];<br>Strategic Planning [5];<br>scenarios [4];<br>dynamic / adaptive [3];<br>decision making / theory [2];<br>decision support [2];<br>models / modeling [2] | 2005 - 2010 |
| Belanger, Micheline[3];<br>Guitouni, Adel[2] | DRDC-Valcartier, Quebec, QC, Canada [3]; | Allouche, Mohamad [1];<br>Bentahar, J. [1];<br>Happe, Jens [1] | decision making / theory [2];<br>dynamic / adaptive [2];<br>centre of gravity (COG) [1];<br>conceptual graphs / models [1];<br>Course of action (COA) [1];<br>decision support [1];<br>effects-based [1];<br>knowledge-based [1];<br>models / modeling [1];<br>risk analysis [1] | 2009 - 2011 |
| Lamoureux, T. M.[3];<br>Rehak, L. A.[3] | Humansystems Inc., Guelph, ON, Canada [2];<br>DRDC Toronto, ON, Canada [1] | Bruyn Martin L. [2];<br>Bandali, F. [1];<br>Bos, J. C. [1] | decision making / theory [3];<br>effects-based [2];<br>models / modeling [2];<br>Simulation [2];<br>Course of action (COA) [1];<br>dynamic / adaptive [1];<br>scenarios [1] | 2006 - 2007 |
| Boukhtouta, A.[2] | DRDC-Valcartier, Quebec, QC, Canada [2]; | Boukhtouta, A. [2];<br>Bedrouni, A. [1];<br>Berger, J. [1];<br>Bouak, F. [1];<br>Guitouni, Adel [1] | Course of action (COA) [1];<br>decision making / theory [1];<br>decision support [1];<br>real-time [1];<br>uncertainty [1] | 2002 - 2004 |

| Author Name(s) | Affiliation of Author | Co-Authors | Top Subject Groups | Publication Years |
|---|---|---|---|---|
| Bruyn Martin L.[2] | DRDC Toronto, ON, Canada [1]; | Bruyn Martin L. [2];<br>Lamoureux, T. M. [2];<br>Rehak, L. A. [2];<br>Bandali, F. [1];<br>Bryant D. [1] | decision making / theory [2];<br>Course of action (COA) [1];<br>effects-based [1];<br>models / modeling [1];<br>Simulation [1] | 2006 - 2007 |
| Bryant, D. J.[2] | DRDC Toronto, ON, Canada [2] | | conceptual graphs / models [2];<br>decision making / theory [2];<br>models / modeling [2];<br>collaborative [1];<br>decision support [1];<br>dynamic / adaptive [1];<br>graphical [1] | 2006 - 2008 |
| Moulin, B.[2] | Université Laval, Quebec, QC, Canada [2]; | Belanger, Micheline [1];<br>Bentahar, J. [1];<br>Haddad, H. [1] | conceptual graphs / models [2];<br>Course of action (COA) [2];<br>models / modeling [2];<br>causal analysis [1];<br>decision making / theory [1];<br>dynamic / adaptive [1];<br>graphical [1];<br>knowledge-based [1];<br>scenarios [1] | 2010 - 2010 |

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