Collaborative Decision Making in a Simulated Stability Operations Exercise: A Prototype Decision Support Tool

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Abstract

We report the results of a collaborative decision making exercise using a simulated stability operations task. The exercise allowed Canadian Forces personnel to experience first-hand the benefits and challenges of taking an integrative decision making approach (i.e., with information and resource sharing) compared to a stovepipe approach (no communication and partial view of the whole system). While teams generally achieved greater mission success in the integrated condition, they could only partially cope with the complexity of such an endeavor. A training session on systems thinking and collaborative design generally improved integrated planning effectiveness. We designed a decision support tool capable of suggesting an effective integrated course of action based on qualitative information about system structure and effects. The tool essentially relies on an innovative 'action-oriented' cross-impact matrix and decision matrix that jointly allow deriving a viable resource allocation given a range of intervention options. The prototype tool aims to be simple and generic for use in real-life applications. The system's inputs are based on simple user judgments (i.e., mental models). We show that the tool provides solutions superior to most human teams. Future research will test the generalization of the approach and assess human ability to refine the tools' solutions.

Keywords: Complex decision making, comprehensive approach, collaboration, decision support, experimentation, simulation.

1. Introduction

Contemporary researchers and practitioners in numerous domains including the natural sciences, social sciences, cognitive science and operations research are increasingly aware of human limitations in understanding and influencing complex adaptive systems (Goldstone & Sakamoto, 2003; Miller, 1982; Rousseau, 2003; Senge, 1990). For instance, one response from numerous nations to this issue has been to progressively adopt a comprehensive approach (or whole of government approach) to Defence and Security issues (Leslie, Gizewski, & Rostek, 2008). This approach recognizes that many contemporary problems and crises require a system-of-systems perspective in order to achieve goals while avoiding the creation of new problems unintentionally. A comprehensive approach means employing and aligning resources (diplomatic, defence, development, and commercial) from numerous agencies, and coordinating these operations through an integrated campaign plan. This approach fundamentally relies on the ability of human teams to make sense of a complex situation by combining different perspectives and expertise through a systemic understanding of the problem in order to design an effective strategy to reach the desired end state. Team sensemaking is defined as the process by which a team manages and coordinates its efforts to explain the current situation and to anticipate future situations, typically under uncertain or ambiguous conditions (Klein, Wiggens, & Dominguez, 2010).

The present study is built around an exercise which aims to provide trainees with first-hand experience on the value and the challenges of adopting a comprehensive approach to Canadian Forces operations. Furthermore, this study involves the development of a decision support tool and the initial assessment of its underlying decision heuristic by comparing the system's proposed solution to human results from the exercise. This tool is akin to previous work by Vester (2007), who developed a generic model-based management tool called the sensitivity model (Malik Management Zentrum St. Gallen). Unlike the sensitivity model, the tool proposed herein keeps the user modeling component to a strict minimum (basic judgments on system state and relations) and does not enable what-if simulations. Rather, it focuses on extending the cross-impact matrix concept (i.e., a matrix describing the systemic impact of each variable on the whole system) to allow deriving effective courses of action from it.

The current exercise is focused on civil-military collaboration, yet the approach and tool put forward in the following paper are essentially generic and applicable to a wide variety of complex domains. The simulation-based exercise seeks to put in contrast a stovepipe and an integrative decision making approach. Furthermore, we seek to provide an initial assessment of the value of a short 3-hour training package on complexity and collaborative sensemaking by comparing a group with training and a group without such training. Part of this training is based on the systemic operational design (SOD) methodology initially developed by Brigadier General (Retired) Shimon Naveh to support team sensemaking and recently integrated into U.S. military doctrine:

> "Mastery of the art of design is not the only ingredient of mission success, but undertaking a mission in a complex environment without design may invite failure. Complex situations—by their very nature—present commanders with special challenges. To comprehend the situation requires deep study and reflection on the underlying system before engaging in action. For these reasons, leaders must understand the nuances associated with the structure of the problems that they will encounter. Design has significant potential as a methodology that allows planning to proceed from a systemic understanding of the situation." (Banach, 2009, p. 103)

SOD, as currently implemented by the United States School of Advanced Military Studies (Fort Leavenworth, Kansas), involves three primary outputs (represented in textual and graphical form): an environmental frame, a problem frame, and a design concept. These artifacts capture the shared understanding of the operational environment, of the problem space, and the solution space. The design concept defines a planning directive that seeks to exploit the transformative potential of the system's tensions. This is usually expressed as a strategy with a set of interdependent and mutually reinforcing lines of effort that organizes interventions as patterns in space and time (Banach & Ryan, 2009). SOD is in essence a framework for structuring team cognition in complex environments (Sorrells, Downing, Blakesley, Pendall, Walk, & Wallwork, 2005).

The present paper is organised as follows. Following this introduction, Section 2 presents the exercise and the method used for data collection. Section 3 presents the results of the exercise. Section 4 describes a new decision support tool designed to help future teams achieve greater mission success by proposing a relatively simple and generic but very effective decision heuristic. Section 5 discusses the implications of our findings for training and supporting integrative decision making in complex and dynamic environments.

2. Method

Participants. 32 officers and sailors of the Canadian Naval Reserve (mean age: 34.4 y, SD: 6.6) participated in the exercise either at Naval Reserve Headquarters (Québec, QC) or at Her Majesty's Canadian Ship (HMCS) STAR (Hamilton, ON). Participants were grouped in teams of four and randomly assigned one of two roles (security or development – including two of each per team). Four out of the eight teams were given a training session (described below) on systems thinking and collaborative design during the course of the exercise (i.e., referred hereafter as the condition with training).

Apparatus. The exercise was run using four standard networked computers. The simulation was controlled using the complex decision making experimental platform (CODEM; Defence R&D Canada), a Java-based application designed for cognitive engineering research and for training complex decision making skills individually or in teams. This simulator provides very good experimental manipulation and data logging capabilities. The flexible scenario editor allowed creating a counter-insurgency and stability operations scenario (Lafond & DuCharme, 2011) which was adapted herein for a multiplayer context. In this scenario, participants are in charge of stabilizing a failing state in the midst of a rising insurgency. Mission duration was set to a maximum of seven simulated game-turns (i.e., 6-month periods). Participants could allocate resources and assets called "action points" to seven different intervention types:

- Security operations
- Influence operations
- Cultural training
- Humanitarian aid
- Training of local forces
- Infrastructure development
- Governance capacity building

Each role (security or development) had access to a limited subset of these interventions options. The state of the situation in given turn was described through nine variables ranging from 0 to 20:

- Host-nation governance
- Population allegiance
- Local media
- Criminality suppression
- Socio-economic welfare
- Local forces
- Infrastructures
- Cultural understanding
- Insurgency suppression

In the simulation, these nine variables mutually influence each other so that each decision results in a chain of effects within the system. Depending on its current value, each variable can be in a desirable or undesirable state as described by a three-color scale that goes from green to orange to red. Feedback on the changes occurring in the situation is provided during the transition from one turn to the next. The goal of the participant is to bring all eight dimensions (cultural understanding is a mediating variable but not a sub-goal) outside of the "critical" (red) state in seven turns or less (this goal can be achieved in four turns). The mission has failed if the allegiance of the local population falls to zero. The underlying model captures several key characteristics of complex dynamic systems (reinforcing and balancing feedback loops, delayed effects, uncertainty, opacity, etc.). Figures 1 through 4 illustrate the different tabs of the CODEM interface (in the integrated system perspective).

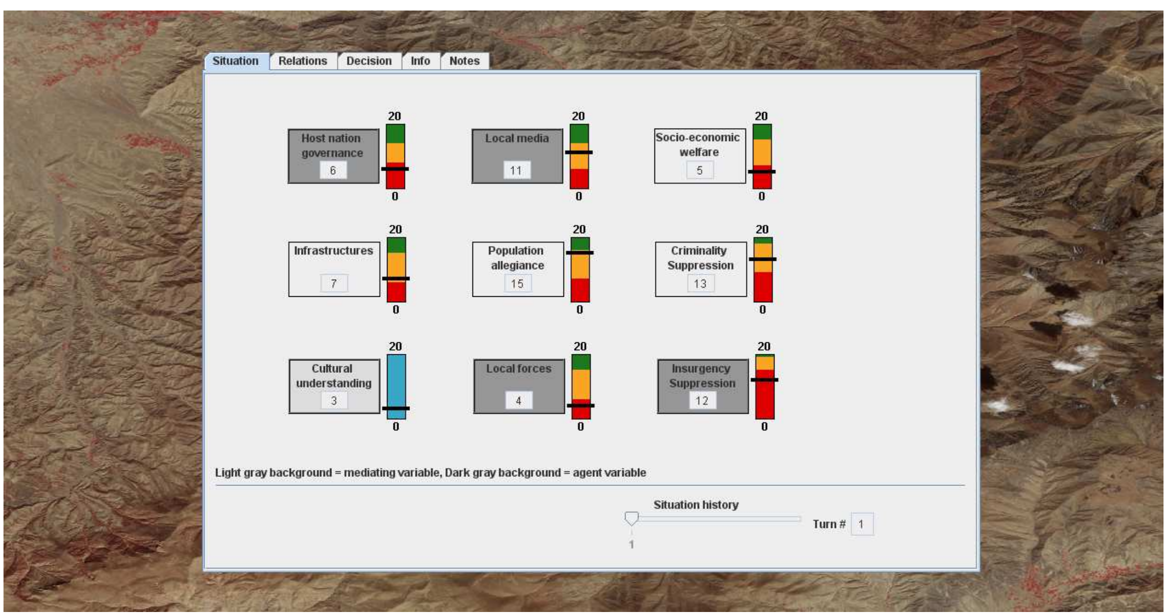

Figure 1. Situation tab showing the current value of system variables. White boxes are for standard variables, dark boxes refer to agents, and grey boxes indicate mediating variables.

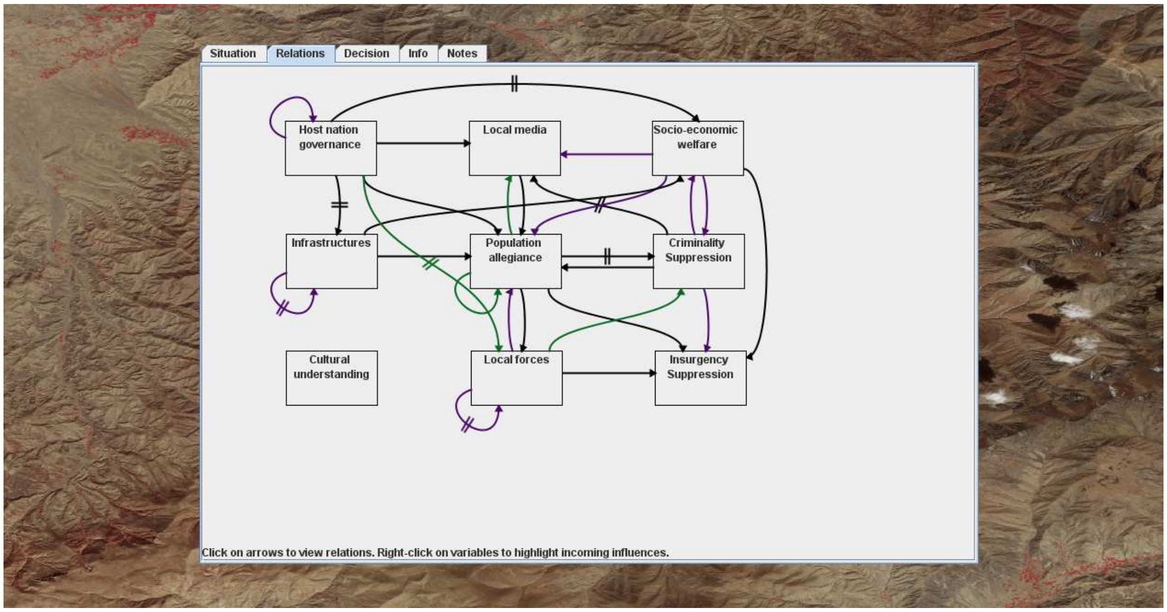

Figure 2. Relations tab showing the interactions between variables. Double-bars indicate delayed effects. Green arrows indicate relationships that increase the value of a variable, while purple means that it decreases it and dark means that the current impact in neutral.

Figure 3. Decision tab showing the different intervention options available, the current amount of resources (action points) available, and factors influencing action points that will be available in future turns. In the integrative version, players can send action points to others and can view the collective intervention before committing to it.

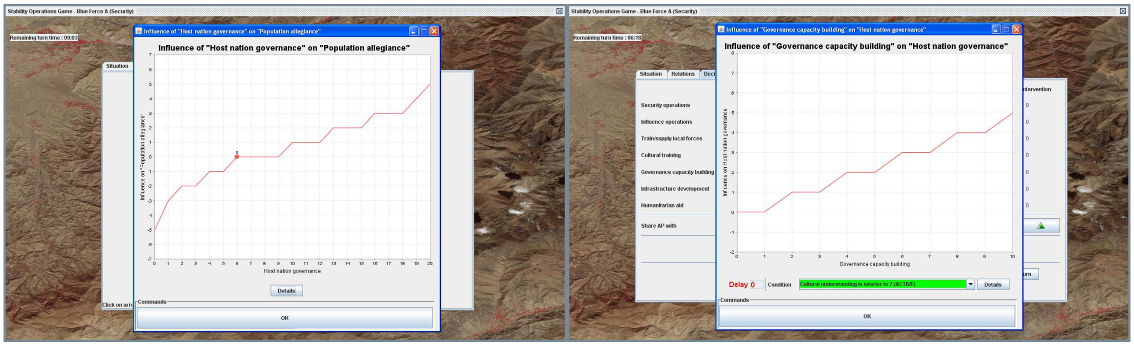

Figure 4. Graph showing the effects of a variable (*x*-axis) on another variable (*y*-axis). The left panel shows an example relation between two variables. The right panel shows one of the effects of an intervention (the x-axis represents the number of action points allocated to that intervention). Effects can include delays and can be roughly linear or highly non-linear. Effect can also be conditional (green bar) and vary according to the current situation.

Design and procedure. In both conditions (with and without training), the exercise begins with a 25-min tutorial and practice on how to interact with the CODEM interface. Each team then performs three successive trials of the stability operations scenario. Trial 1 and Trial 2 are identical. Both involve playing the scenario in a stovepipe manner (i.e., without communication or resource sharing). In these two stovepipe trials, participants have a partial view on the system (variable states and interrelations). In Trial 3, all four participants can view the whole set of variables and interrelations. Furthermore, they can now discuss at will to share information, share resources and collaboratively design their mission strategy. The task involves mild time pressure (10 minutes limit per turn) added mainly to control exercise duration.

In the condition without training, the full exercise is completed in four hours. In the condition with training, the exercise is subdivided into two sessions. Session 1 includes the 25-min familiarization followed by Trials 1 and 2. Session 2 includes a 3-hour training package on systems thinking and collaborative systemic operational design, followed by Trial 3 of the stability operations scenario. The training session included an introduction to systems thinking and a summary of best practices for decision making in complex environments (Armenis, 2007; Dörner, 1996). Trainee’s then perform an individual practice session with a novel Arctic Operations scenario which includes an intelligent tutor designed to intervene when poor decision heuristics appear to be used (see Lafond, DuCharme, Rioux, Tremblay, Rathbun, and Jarmasz, 2012, for details). This 30-min. practice session aims to improve integration of the previous educational material and seeks to familiarize the players with the scenario in preparation for the ulterior collaborative trial of this same scenario. Following a short break, participants received an introduction to systemic operational design (Banach & Ryan, 2009; Wass de Czege, 2009) and how each stage can help collaboratively solve complex problems such as those presented in the CODEM simulations. Systemic operational designed was presented as a structured synthesis of the best practice for complex decision making applied to a collaborative decision making context. Following this presentation, participants played the Arctic Operations scenario collaboratively to practice systems thinking in teams. The exercise concluded with third (integrative) trial of the stability operations scenario and a debriefing.

Performance metric. Performance is measured by the relative distance from the eight sub-goals, and is based on the proportion of the seven-year mandate completed, resulting in a scale ranging from 0 to 100. Hence, reaching the mission goal at the end of the seventh turn (the last turn) does not yield a score of 100. A score of 100 is attributed to reaching the goal in as few turns as possible (i.e., on Turn 4 in this particular scenario).

3. Results

While sample size at this point is too small to perform reliable statistical analyses for inference to the larger population, we report the results of the eight four-person teams having participated so far in this exercise to provide an initial assessment of its value. As such, these results provide a proof of concept that the effects reported below can occur but we cannot reliably ascertain that these results will be replicated with a different sample. Figure 5 shows the average performance of the eight teams across the three sessions of the stability operations scenario.

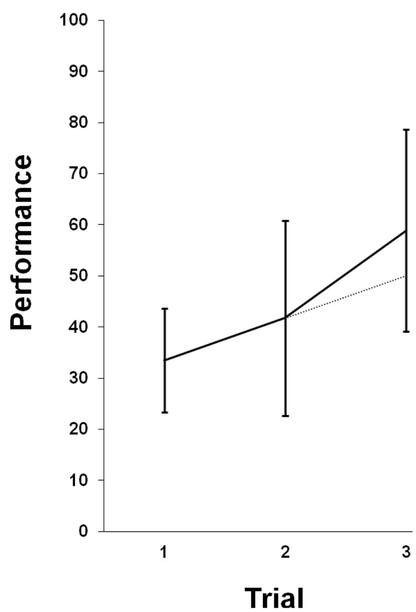

Figure 5. Team performance for Trial 1 (stovepipe, M=33.5%), Trial 2 (stovepipe, M=41.75%) and Trial 3 (integrative, M=58.88%). Error bars show the standard deviation. The dotted line shows the linear projection of the practice effect estimated from Trial 1 and Trial 2.

Effect of practice. Due to the repeated measures design of this exercise, the increased chance of succeeding when repeating a scenario must be estimated in order to factor out this effect when considering the impact of other factors. The practice effect was defined as the difference between the average score of Trial 1 (33.5%) and Trial 2 (41.75%). The estimated practice effect based on our sample is an increase in performance of 8.25% per trial. This estimate follows a conservative approach which assumes that the practice effect is linear (the same across trials), while in fact the practice effect is known to progressively diminish across trials following a power law (Ritter & Schooler, 2001). Note that this possible overestimation of the practice effect may result in an underestimation of the effects of the training session and of the integrative condition.

Effect of training session. Defined as the difference between the two deltas of Trial 2 and Trial 3 associated with the two conditions (with vs. without the training session), minus the practice effect. The estimated effect of the training session is a 5.75% increase in performance.

Effect of integrative condition. Defined as the increase from Trial 2 to Trial 3 minus the practice effect and the training session's effect. The estimated impact of the integrative condition is a 6% increase in performance.

Combined, the estimated impacts of the training session (5.75%) and of the integrative condition (6%) produced an improvement of 11.75% on performance.

For comparison purposes, we simulated random responding over 300 trials to better assess the likelihood of achieving a minimal score without any understanding of the system. The average score obtained randomly was 30.2% (SD = 7.96) compared to humans which was 44.7% (SD = 19.43). It turns out that 25% of human trials yielded a score below the expected chance level. Yet on all these occasions but one, this result may be attributable to the fact that decision makers where in a stovepipe condition in which their actions were uncoordinated (i.e., potentially conflicted).

4. Decision Support Tool

Clearly, the exercise showed that despite the benefits of practice, collaboration and the training session, participants only partially managed to cope with the complexity of such an endeavor, leaving much room for improvement. In real-world civil-military operations, even marginal improvements in decision-making can lead to signification reductions in loss of life, destruction of the environment and infrastructure and resource expenditures. Still, one potential limitation of the training session is that although it specified useful behaviors to adopt (e.g., understand interrelations or "tensions" in the system to find leverage points, consider side-effects of decisions, etc.), no specific metrics or strategies were operationalized to actually specify how to perform this system analysis to come up with a viable course of action. We therefore proceeded to design a decision support tool (e.g., for use in a systemic operational design context) capable of suggesting an effective integrated course of action based on qualitative information about system structure and effects.

Tool overview. The tool, implemented in Excel, involves an innovative form of cross-impact matrix aligned with the goal structure, combined with a complementary intervention effects matrix designed to assess the relative cost-benefit ratio of each action. The resulting index associated with each action then determines the relative level of effort to place on each intervention. Furthermore, this assessment is situation-dependent as well, updating the required resource allocation as the state of variables changes over time.

Tool inputs. The prototype tool aims to be simple and generic for use in real-world situations. The system's inputs are based on simple user judgments (i.e., mental models). First, the user must identify the system variables and represent their current state on a semi-quantitative scale (e.g., a simplified 0-20 scale as in CODEM). Next, the user must identify each of the relations between variables, by making the following two judgments:

1) In respect to your goals, when variable *x* is very low, is its effect on *y* positive, neutral or negative and is that effect small, medium or large?

2) In respect to your goals, when variable *x* is very high, is its effect on *y* positive, neutral or negative and is that effect small, medium or large?

These two judgments essentially mean creating a matrix (shown in Table 1) with values inside representing how desirable (1, 2, 3) or how undesirable (-1, -2, -3) that state is in relation to the user's goals or desired end state.

Table 1. Input matrix to characterize the effect of a variable *x* on *y*.

Large positive effect	3	3
Medium positive effect	2	2
Small positive effect	1	1
Neutral effect	0	0
Small negative effect	-1	-1
Medium negative effect	-2	-2
Large negative effect	-3	-3
	Effect when *x* is very low	Effect when *x* is very high

Each relation is therefore characterized by a value in each column. By calculating the slope of that function, we obtain a simple estimate of the value for the decision maker to achieve an increase in that variable. For example, "-2 and 1" yields a slope of 3, whereas "3 and -2" yields a slope of -5, and "-1 and 3" yields a slope of 4. The first example shows that this function is aligned with one of the task's subgoals, while the second example goes against a subgoal. Furthermore, note that the third example is more strongly (4) in line with a subgoal than the first example (3). Note that a variable that always had large negative effects will result in a slope of zero. This means that such an effect will basically be ignored here since a change in the value of *x* will not make the system's behavior more or less desirable (keeping that variable low or increasing it will not improve the situation). Hence, the present approach is goal-oriented rather than system-focused.

Cross-impact matrix. This matrix specifies the effects of each system variable (rows) on each system variable (columns), including itself if applicable. This matrix essentially catalogs the value of the slope derived for each relation identified by the user. On the right end of the matrix each row's total represents the systemic impact "*of a potential increase*" in that variable on other variables in relation to the overall goal-structure. Negative and positive values are allowed to cancel each other out. A positive total means the user should seek to increase the value of that variable. A negative value means the user should keep the value of that variable as low as possible. Each cell in the cross-impact matrix is also context sensitive. When variable *x* is at the maximum value a cell with a positive slope should no longer have a high value since increasing that variable cannot lead to further benefits. Conversely, when a slope is positive and variable *x* is at its minimal value, then it there is a maximal benefit in improving that variable. Each slope in the cross-impact matrix is therefore multiplied by [1-(current value of *x*/maximal value of *x*)] if it is positive and by [current value of *x*/maximal value of *x*] if it is negative. The weighted total at the right of each row corresponds to the total for that row divided by the sum of the totals for each row. Table 2 illustrates the resulting matrix for the stability operations scenario.

Table 2. Goal-oriented cross-impact matrix derived from the stability operations scenario.

	HG	LM	SW	I	PA	CS	CU	LF	IS	Total	Weight
Host Nation Governance (HG)	0.00	4.00	5.00	2.00	6.00			2.00		19.00	0.18
Local Media (LM)					6.00					6.00	0.06
Socio-Economic Welfare (SW)		4.00			5.00	3.00			0.00	12.00	0.11
Infrastructures (I)			4.00	0.00	4.00					8.00	0.07
Population Allegiance (PA)		4.00			2.00	3.00		2.00	5.00	16.00	0.15
Criminality Suppression (CS)		6.00	3.00		3.00				2.00	14.00	0.13
Cultural Understanding (CU)	1.00	1.00			3.00	1.00		1.00	1.00	8.00	0.07
Local Forces (LF)					5.00	2.00		0.00	2.00	9.00	0.08
Insurgency Suppression (IS)	2.00	2.00		2.00	2.00	2.00		3.00	2.50	15.50	0.14
Total	3.00	21.00	12.00	4.00	36.00	11.00	0.00	8.00	12.50	107.50	1.00

Note. Based on the situation at the beginning of the scenario. An average slope is calculated in the case of conditional relations involving more than one function.

Decision matrix. Now that the set of interrelations between system variables is defined, the next step is to consider the systemic impacts of the set of interventions being considered. This involves mapping the different potential effects of each intervention on the system variables using the input matrix described in Table 1. Furthermore, each value (slope) is multiplied by the systemic importance of that variable (the weight value of the variable on the rightmost column of the cross-impact matrix). The resulting weights at the rightmost end of the decision matrix determine the relative proportion of effort (i.e., resources or action points) to place on each type of intervention at that point in time. In short, the decision matrix tells us the (relative) extent to which each intervention has a *desirable* impact on variables having themselves a *desirable* impact on other variables. Table 3 shows the decision matrix derived for the stability operations scenario.

Table 3. Decision matrix for the stability operations scenario (on Turn 1).

	HG	LM	SW	I	PA	CS	CU	LF	IS	Total	Weight
Security Operations		-.17			0.00	0.20			0.36	0.39	0.10
Influence Operations		0.08			0.30				0.24	0.62	0.16
Cultural Training							0.30			0.30	0.08
Humanitarian Aid		0.14	0.33		0.60				-.29	0.78	0.20
Train/supply Local Forces								0.25		0.25	0.06
Infrastructure Development				0.22	0.52					0.74	0.19
Governance Capacity Build.	0.53				0.30					0.83	0.21
Total	0.53	0.06	0.33	0.22	1.71	0.20	0.30	0.25	0.31	3.91	1.00

Tool effectiveness. As an initial test to determine if the decision support tool can provide effective guidance to decision makers, we tested its effectiveness on the stability operations scenario. Results yield a score of 66%, which was significantly superior to the results of human teams across all trials, $t(23) = 5.37$, $p < .001$. The tool's proposed strategy allowed the Blue Forces mission to reach end of the maximum mission length without losing. It did not quite achieve the win condition however (winning on the last possible turn corresponds to a score of 72%). Still, this result is superior to the average score of human teams on Trial 1 (33.5%), on Trial 2 (41.75%) and on Trial 3 (58.88%). Humans did better than the tool on five out of twenty-four trials, yet when factoring out the practice effect (in the real world there is only one shot at this) the tool always did better. The human average across the 24 trials with the practice effect removed for Trial 2 and Trial 3 was 36.6%, which means that the tool's proposed strategy was on average 30.4% better.

Clearly this tool could have been very useful to human teams by proposing a viable draft course of action. Since the logic behind the tool is transparent, decision makers could use that logic to understand why certain interventions should be given higher weights and perhaps even improve on the tool's proposed solutions, thus combining the complementary strengths of the tool (information integration) and of human decision makers (learning and adaptability).

5. Discussion

The collaborative decision making exercise reported herein allowed Canadian Forces personnel to experience first-hand the benefits and challenges of taking an integrative approach to solving complex problems. The training session on systems thinking and collaborative systemic operational design had an overall positive impact on integrated planning effectiveness. Furthermore, teams generally achieved greater mission success in the integrated condition even when factoring out the estimated practice effect. Despite the apparent benefits of the above interventions observed in this exercise, most of the teams only partially overcame the complexity of that simulated mission.

We designed a decision support tool capable of suggesting an effective integrated course of action based on qualitative information about system structure and effects. The tool essentially relies an innovative 'action-oriented' cross-impact matrix and a decision matrix allowing to derive viable context-sensitive resource allocations given a range on intervention options.

Tool limitations and possible extensions. One key limitation of the present approach is that it assumes system relations and decision effects to be linear. It might be possible to capture non-linear relations (e.g., u-shaped relations for instance - which actually occurred in the stability operations scenario) by adding a third column to the input matrix representing the middle value of a variable. However, this would require rethinking the overall slope calculation method and would come with a cost in complexity for the user. A second limitation is that the current approach ignores delays. An extension taking delays into account would significantly increase the value of the tool in contexts which large delays (delays in the stability operations scenario only postponed effects for one turn). A third limitation is that the effectiveness of the tool ultimately depends on mental model accuracy. In a more opaque context where interrelations are not clearly represented to users as in the present exercise, the tool's inputs will likely involve a degree of error that will reduce the tool's effectiveness (yet basic human effectiveness will be impeded in such a context as well, so the relative benefit of the tool may remain high). A fourth limitation is that only the first degree systemic impact of variables is considered. Indeed, recursive could potentially yield superior results by deepening the analysis to third-order and higher order effects, but this may be achieved at the expense of simplicity and transparency to the user. A fifth limitation is that the present model assumes that resources can be used interchangeably for different types of interventions. In the real-world, while financial assets have this desirable property, human and physical assets typically dispose of capabilities appropriate for certain types of interventions.

In addition to these limitations, there are also human strengths that could complement and help refine the strategies proposed by the tool. Humans are adept at learning from feedback and may learn to fine-tune interventions as they accumulate experience. For instance, in some cases there is no noticeable gain between a small or moderate intervention. Humans becoming aware of this may thus appropriately shift useless efforts to a different line of operations that would yield benefits from this extra effort. Furthermore, human decision makers are adept at using satisfycing strategies to reach a goal more effectively. For example, when approaching the convergent satisfaction of multiple goals, the tool will continue proposing the most effective long term strategy taking advantage of leverage points, yet this may unnecessarily prolong the mission. Humans can at some point focus on the minimal requirements to succeed and engage in short term tactics to 'win' in a more timely manner. Nonetheless, it may be argued that such satisfycing strategies may lead to a less stable end state.

Importantly, the decision support tool does not presume to lead to automated course of action development in real-world applications, i.e., “blind” decision-making based on the outputs of a basic model. The tool crudely interprets the complexity of the system and mathematically derives a recommended solution. The tool’s recommended resource allocation may not always be feasible, implementable or in line with an overarching military strategy. This means that a human decision-maker will always be “in the loop.” The tool essentially reduces the complexity of the solution space for decision makers, by “taking obviously bad, and not-so-obviously-bad, decisions off the table.”

Future research will test if teams of human decision makers can use and refine the decision support tool's solutions owing to each’s own contextual understanding and learning ability. A critical next step is also to assess the generalizability of the approach. If the tool’s validity and effectiveness is proven in the long-term it is conceivable that a future version could be employed prior to (and during) comprehensive or “full spectrum” operations by operational and strategic level integrated planning teams.

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References

Armenis, D. (2007). Dealing with battlefield complexity: A decision maker’s perspective. *Proceedings of the 8th Asia-Pacific Complex Systems Conference*.

Banach, S.J. (2009). Educating by design: Preparing leaders for a complex world. *Military Review. March-April,* 96-104.

Banach, S.J., & Ryan, A.J. (2009). The art of design: A design methodology. *Military Review, March-April,* 105-115.

Dörner, D. (1996). *The logic of failure: Recognizing and avoiding error in complex situations.* Reading, MA: Addison-Wesley.

Goldstone, R.L., & Sakamoto, Y. (2003). The transfer of abstract principles governing complex adaptive systems. *Cognitive Psychology, 46,* 414-466.

Klein G., Wiggens S., & Dominguez C. (2010). Team sensemaking. *Theoretical Issues in Ergonomics Science, 11,* 304-320.

Lafond, D., & DuCharme, M.B. (2011). Complex decision making experimental platform (CODEM): A counter-insurgency scenario. *Proceedings of the IEEE Symposium on Computational Intelligence for Security and Defence Applications.* Paris, FR, April 11-15, pp. 72-79.

Lafond, D., DuCharme, M.B., Rioux, F., Tremblay, S., Rathbun, B., & Jarmasz, J. (2012). Training systems thinking and adaptability for complex decision making in defence and security. *Proceedings of the IEEE Conference on Cognitive Methods in Situation Awareness and Decision Support.* New Orleans, LA, March 6-8, pp. 51-58.

Leslie, A., Gizewski, P., & Rostek, M. (2008). Developing a comprehensive approach to Canadian Forces operations. *Canadian Military Journal, 9,* 11-20.

Miller, A. (1982). Tunnel vision in environmental management. *The Environmentalist, 2,* 223-231.

Ritter, F.E., & Schooler, L.J. (2001). The learning curve. In W. Kintch, N. Smelser, P. Baltes, (Eds.), *International Encyclopedia of the Social and Behavioral Sciences* (pp. 8602-8605). Oxford, UK: Pergamon.

Rousseau, C. (2003). Complexity and the limits of modern battlespace visualization. *Canadian Military Journal, Summer,* 35-44.

Senge, P.M. (1990). *The fifth discipline – The art and practice of the learning organization.* New York, NY: Currency & Doubleday. 1990.

Sorrells, W. T., Downing, G. R., Blakesley, P. J., Pendall, D. W., Walk, J. K., & Wallwork, R. D. (2005). *Systemic operational design: An introduction. Fort Leavenworth: School of Advanced Military Studies.* United States Army Command and General Staff College.

Vester, F. (2007). *The art of interconnected thinking: Ideas and tools for tackling with complexity.* MCB: Verlag.

Wass de Czege, H. (2009). Systemic operational design: Learning and adapting in complex missions. *Military Review, Jan.-Feb.,* 2-12.