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The Future of C2

Title: Qualitative Simulation of Human Command & Control System Effectiveness
Topic: Assessment, Tools, and Metrics

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Abstract

Capturing information for performance modeling of the human aspect of C2 performance can be difficult and time consuming. Usually, a parametric approach is favored, but overall, technology performance is used to calibrate performance. It is difficult to determine or assess the aspects of human performance in the technologically driven C2 systems. This paper presents a novel approach using a qualitative evaluation metric based on fundamental matrix algebra. It is assumed that the performance of C2 to be achieved can be speculated by the commanders based on units to be commissioned and technological capabilities of the units. The ACAD software which allows commanders to simulate courses of action planning based on battle assets is used to demonstrate the model efficacy. The model illustrates the composite measure of C2 based on mission, as well as unit effectiveness based on the expectations of the higher command.

INTRODUCTION

In the military domain, command and control (C2) are the civilian equivalents of leadership and management. Leaders are the persons who must give directives and set goals for a defined mission. Similarly, the managers are tasked with coordinating resources to carry out the mission. While the leader reasons at the highest level of the task abstraction, the manager operates at the middle to atomic levels of the system hierarchy which is usually translated into actions. In essence, the manager is responsible for controlling activities, and he/she is controlled from above by the commander. In either level, some sort of performance is used to guide in the operation of the system.

Today, advanced technologies are to enhance C2 as this enables effective force integration and sustainment of doctrinal, organizational, and equipment integration. Moreover, because of the technology component, quantitative models have been favored to support performance analysis of C2 systems (Biswas, Kapadia, & Yu, 1997; Raghunathan, 1997). As the human is somehow always in the loop, the human

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component of the C2 performance is not easily assessed with quantitative models. This paper proposes a qualitative approach to the performance evaluation of human C2 (HC2) systems.

Qualitative models allow researchers to explore how people perceive specific issues based on observations which recognize that reality is constructed and shaped by the experience (Say, 1999). In the HC2 dimension, we are dealing with issues like tacit knowledge which is difficult to share, the changes in organization, and unpredictable nature of tasks. Examples of these situations are ubiquitous today in the global war against terrorism or coalition emergency response to tsunamis crisis in Asia. In the current situation in Iraq, data are available to measure the performance of technology used in the C2 systems. The same cannot be said for the measure of performance effectiveness of the commanders due to the conflicting and unpredictable chaos resulting from the asymmetric tasks. Therefore, qualitative methods are appropriate to investigate C2 performance in these kinds of situations. This is because they are based on a form of inquiry concerned with understanding human behavior, tasks, activities, and actions in a more holistic manner (Zarakovsky, 2004).

In general, qualitative modeling is based on systems thinking and theoretical description paradigms using abstractions, gap analysis, differences in behavior and structural networks, etc. From some of his earliest published papers (Keeney, 1990) has explored the many varied possibilities of a cybernetic understanding of qualitative discourse as a form of qualitative metric for HC2 system. For example, by observing the patterns of behavior one he established that system performance is regulated by the discrepancies inherent in the system over time.

MODEL DEVELOPMENT

A systems view of C2 is a mirror view of an organizational design with its top-down information flow. At the command level, it is the leaders (in the military lexicon, the commanders) that issue command to the subordinates. Traditionally, leaders are performance or goal oriented. In other to make sure the goal is achieved, control measures are established at the relevant information (C2) points.

Managers are appointed to manage the behaviors of the aforementioned control points and they do so by enacting control laws necessary to bring the elements of the system to perform in a way to achieve the system level goals and satisfy the basic requirements. This is the essence of control law such as self-regulating, variance reduction, error cancellation, and so forth (Olivier & Gouze, 2002). The control law ascribes the boundaries of system design subject to anticipated performance, and is also responsible for feedback communication between the various levels of control points

In the status quo, the commander is conditioned to exercise control (Figure 1). Assume that the commander has a goal aspiration measured by the vector $\mathbf{A}$ of size n containing the commander's aspiration measures. Let the control system be assigned the achievement level $\mathbf{H}$. $\mathbf{H}$ is a matrix in which a vector of size m (corresponding to the control points or number of controllers) is mapped into the commander's aspiration vector.

Mathematically, the actual performance at the command level is defined by weighted vector

$$\mathbf{P} = \Delta \mathbf{A} / \boldsymbol{\Omega} \qquad \textbf{(1)}$$

where,

$$\boldsymbol{\Delta} = \mathbf{H}^T \mathbf{I}, \mathbf{H}\ \mathbf{(nxm); I(mxm)} \qquad \textbf{(2)}$$

$$\Omega_i = \text{Row Sum}_i\,(\Delta) \qquad (3)$$

Similarly, we can compute the overall C2 performance expectation denoted by **C**

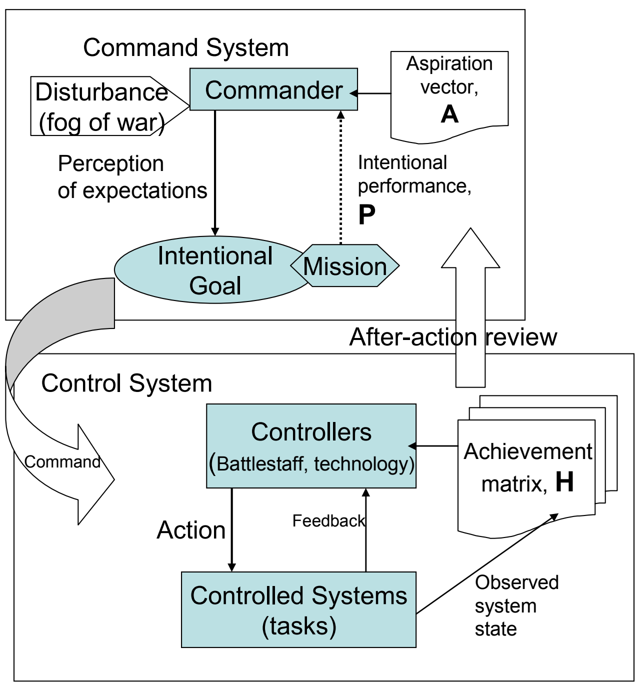

Figure 1. Sample generic C2 architecture

$$\mathbf{C} = \mathbf{A}^T \mathbf{W} / \mathbf{Sum(W)} \qquad \textbf{(4)}$$

$$\mathbf{W} = \mathbf{H}^T * \mathbf{U} \qquad \textbf{(5)}$$

I is a matrix with elemental values (I_{ij}) equal to 1 or 0 indicating whether a control point j is tasked to satisfy the command aspiration value a_i.

SIMULATION EXPERIMENTS

The ACAD software (Ntuen & Park, 2003) was used in the proof-of-concept study. The course of action analysis is based on "Force-on-Force Strength Matching

(FOFSM)”. Under the FOFSM algorithm, a predefined enemy force structure is played against the commander’s (friendly) selected force structure. A selection of a force structure defines a COA with battle asset configuration. Each COA outcome is determined by the FOFSM algorithm which computes several measures of performance, including effectiveness, attrition (for personnel and weapons), event posture residency time, and posture risk and probabilities.

The ACAD has a built-in set of Tables of Organization and Equipment (TOE) for the friendly and enemy forces for each level of the unit or troop composition. Each TOE defines the number and types of combat units to be involved in a battle. Selecting a resource block in the ACAD’s graphical user interface (GUI) automatically references the TOE for use in the analytical models. The ACAD analytical models use the METT-T input information to wargame highly abstracted combats situations.

The ACAD domain provides the use some options to select the desired resource combinations, force strength multipliers, number of friendly course of action (FCOA), predefined enemy course of action (ECOA), planning time (maximum of 120 hours), reserve policy, and the level of surprise. At the end of a wargame, the ACAD displays the relevant measures of effectiveness in a graphical format. The user can visualize this information and use it to determine the best course of action. The ACAD displays the relevant measures of effectiveness in a graphical format. The user can visualize this information and uses it to determine the best course of action. If desired, the ACAD model allows the user to override the computer model’s recommendation. Exhibit 1 shows sample user input screen in ACAD.

As an example problem to illustrate the mathematical formulation, consider a commander who has decided on three aspiration levels as follows: (1) capture terrain with 90% performance, (2) kill or capture the enemy with 95% performance, and (3) deliver humanitarian aid to civilians in the enemy territory with performance of 100%. The control system operates with four different fighting units tasked to satisfy the commander’s aspiration as shown in Table 1. Each of the control points are expected to achieve the following performance levels: 95% for Unit 1, 90% for Unit 2, 100% for Unit 3, and 80% for Unit 4

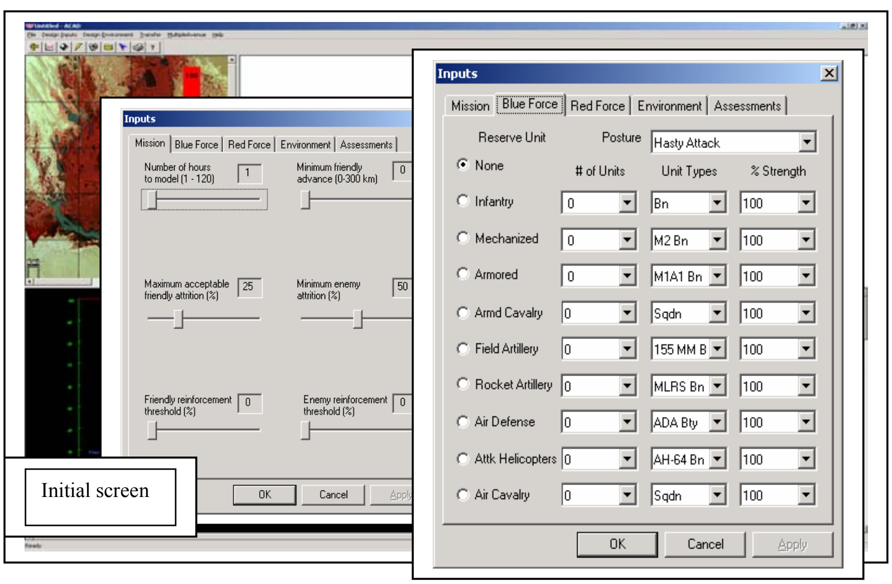

Exhibit 1. Sample ACAD input screen.

Table 1. Mappings of commander's aspiration to unit (control) performance

	Capture terrain (a1)	Kill enemy (a1)	Humanitarian aid (a3)
Unit 1(h1)	0.9	0.0	0
Unit 2 (h2)	1	0	1
Unit 3 (h3)	0	0.8	0.8
Unit 4 (h4)	1	1	1

From the data, the following matrices are obtained:

$$A = \begin{pmatrix} .9 \\ .95 \\ 1 \end{pmatrix} \qquad H = \begin{pmatrix} 0.9 & 1 & 0 & 1 \\ 0.9 & 0 & 0.8 & 1 \\ 0 & 1 & 0.9 & 1 \end{pmatrix} \quad U = \begin{pmatrix} 0.95 \\ 0.9 \\ 1.0 \\ 0.8 \end{pmatrix}$$

By applying the formulas, the achieved command performance against aspirations are computed with results in Table 2.

Table 2. Achieved and expected performance at the command level

Intentional Goal	Expected performance (%)	Achieved (Calculated) performance (%)	Gain/Loss (%)
Capture terrain	90	90.15	+.15 (Gain)
Kill enemy	95	94.92	-0.08 (loss)
Humanitarian aid	100	95.66	-4.34 (loss)

The overall achieved C2 aspiration level is calculated by

(a) $$\mathbf{W} = \mathbf{H}^T * \mathbf{U} = \begin{pmatrix} 0.9 & 1 & 0 & 1 \\ 0 & 0 & .8 & 1 \\ 0 & 1 & .8 & 1 \end{pmatrix} \begin{pmatrix} .95 \\ .9 \\ 1 \\ .8 \end{pmatrix} = \begin{pmatrix} 2.555 \\ 1.6 \\ 2.5 \end{pmatrix}$$

(b) Calculate weighted performance

$$\mathbf{C} = \mathbf{A}^T\mathbf{W}/\mathbf{Sum(W)} = \begin{pmatrix} 0.9 & 0.95 & 1 \end{pmatrix} \begin{pmatrix} 2.555 \\ 1.6 \\ 2.5 \end{pmatrix} \Big/ (2.55 + 1.6 + 2.5) = 0.9496 = 94.96\%$$

RESULT AND DISCUSSIONS

As shown in Table 2, the gain or loss column typifies the error factors obtained from an after-fact mission analysis. The magnitude of the loss determines the severity of the C2 performance. In quantitative C2 analysis, this defines the possible indicator variables of the system to be improved through error minimization objective. Note, however there are may factors that can enter into the equations (including exogenous noise, in this case, new mission assignment) and these factors must be established prior to the actual performance analysis. This is in accordance to the principle of the law of requisite variety by Ashby (1973) which states that the larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate.

One of the applications of a performance metric is to undertake changes in the system so as to further improve performance. In a complex HC2 such as the on-going Iraq war, the use of quantitative metrics is difficult to be used to capture all the nuances and chaos of the system. A qualitative metric proposed will close this loop. This may be at the expense of the use of direct measurement over introspective fuzzy measures. A combination of both qualitative and quantitative measures can be used to obtain optimal solutions (if there is anything like that in a complex C2 system) (Raghunathan, 1997). A system view of the HC2 leads to different measures used in a different way. It means establishing performance metric according to different principles. For example, the **H** matrix can be obtained from technology capabilities assessment factors assigned to the command units.

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