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Efficient Experimental Design Tools for Exploring Command and Control Organizational Structures

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14. ABSTRACT
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ABSTRACT

Armed forces around the world are considering radical transformations to their structures and strategies because of the information revolution and the changing global environment. Senior leadership continually face decisions on how best to structure, modernize, organize, and employ forces in an increasingly uncertain future. For many of these problems analytical methods are not applicable, and large-scale experimentation is not feasible. Simulation provides a valuable tool for addressing these types of problems. One key characteristic of these decisions is the large number of factors, and interactions between factors that impact decision makers. Traditional simulation approaches are not designed to deal with this many factors, therefore the results are often incorrect or misleading. In this paper we introduce and implement efficient design of experiments techniques to analyze C2 organizational models and pursue optimal settings for different performance measures. This allows analysts to rapidly identify the important factors within the simulation, employ an experimental design to fully explore the simulation space efficiently, and design the systems with desired optimal performances with the simulation model. This effort dramatically increases the breadth and depth of insights possible when the simulation output data are analyzed, while reducing the time required for performing a study.

1. INTRODUCTION

In *Joint Vision 2010*, Army General John M. Shalikashvili, Chairman of the Joint Chiefs of Staff, said "The nature of modern warfare demands that we fight as a joint team. This was important yesterday, it is essential today, and it will be even more imperative tomorrow." In light of the critical transformation drive of the U.S. military, innovative organizational structures are needed to deliver better team performance.

How can appropriate organizational structures be identified? One way is via leveraging subject-matter expertise to identify a few specific alternatives expected to yield better performance in complex, dynamic environments; perform the training necessary for teams to operate effectively under these organizational structures; and then conduct some live experiments or exercises to assess whether the new structures are, indeed, effective. However, the costs and time are prohibitive for any broad-scale investigation. It is possible (even likely) that the subject matter experts may not be able to identify the "best" organizational structures *a priori*—precisely because the environment is so complex. This means that even if the physical exercises indicate that improvements in overall performance are possible, these improvements might be far below the "optimal" levels of performance that could be achieved.

An alternative approach involves experimenting on computational models of organizational performance—such as organizations with different levels of "edginess." The basic idea is to save time and money by conducting experiments in the virtual domain. The identification of the most important drivers of organizational performance can provide decision makers with much richer insights into how to deliver better team performance.

Researchers using simulation to explore organizational performance have coined the term "computational organizational theory" for this type of exploration. Yet even in the simulation environment, the studies have typically been limited to a handful of factors or scenarios. But the simulation environment offers challenges and opportunities—the best designs are typically not familiar to those who conduct field or laboratory experiments involving human subjects (Kleijnen et al., 2005). Keys to effective simulation studies are efficient experimental designs and interfaces/infrastructure for automating experiments. In this way, the power of efficient experimental designs is available to an analyst without requiring the analyst to develop expertise in the technique.

In this paper, we describe our recent efforts to enhance the infrastructure for performing large-scale simulation studies on models of organizational performance. Our primary goal is to assist Edge researchers perform large-scale simulation studies using efficient experimental designs. The approach requires a change in mindset for many researchers and analysts who otherwise might not think of exploring more than a handful of factors or scenarios, (see, e.g., Carley and Glasser, 1999; Nissen and Levitt, 2004). Yet the benefits can be dramatic.

The importance of computational experimentation for the analysis of these complex systems is discussed in Gateau et al. (2007). In the paper, the relative multidimensional performances of six theoretically distinct organizational forms are compared, but no strict analysis of each factor's (parameter's) effect on the performance has been stressed (although some initial observations have been made). As the authors state,

> "… *if we can identify the model parameters that enable the Simple Structure to keep risk below that of the Machine Bureaucracy (e.g., formalization), that enable the Professional Bureaucracy to operate so quickly in predictable environments such as the Industrial Era (e.g., application experience), and that enable the Divisionalized Form to keep rework down in predictable environments (e.g., hierarchy)—that is, drawing the best from each organizational form—then we would establish the capability to design an organization that is tailored specifically to a particular environment. Further, if we can identify the model parameters that make each of the various organizational forms more or less effective in terms of responses to manipulations such as enhanced network architecture and increased professional competency, then we would establish the capability to design an organization that is tailored specifically to a particular manipulation. This represents the objective of articulating the organization design space: to facilitate organizational design specific to particular environments and managerial manipulation*."

We have been developing new, state-of-the art experimental designs that allow analysts to achieve these goals with guaranteed correctness. For example, Controlled Sequential Bifurcation (CSB) is a new group screening method proposed by Wan, Ankenman and Nelson (2007). The user specifies two thresholds. Factor effects with true magnitudes below the lower threshold are considered unimportant, those with magnitudes above the upper threshold are considered critically important, and those with magnitudes between the two thresholds are in between. Of course, since the true effect magnitudes are unknown, a procedure that properly identifies the unimportant and critically important effects is needed. CSB does this by grouping factors together and testing the group's cumulative effect. If the group's effect is important, then the group is split into two subgroups for further testing. Otherwise all factors in the group will be classified as unimportant. As experiments proceeds, the groups become smaller and eventually all factors that have not been classified will be tested individually. CSB is most efficient in large-scale cases when the important factors are sparse and grouped together since unimportant factors will be eliminated in groups in early stage. On the other hand, in CSB the signs of the effects have to be assumed pre-known, otherwise the effects may cancel each other in a group and the classifying results can be misleading.

A related technique is called FFCSB, for Fractional Factorial Controlled Sequential Bifurcation (Sanchez, Wan and Lucas 2005, 2008; see also Oh 2007). FFCSB begins with a resolution III fractional factorial design to separate factors into positive and negative groups. Within each group, the factors are ranked based on their estimated effects and CSB is conducted on the ranked factors for classification. Numerical evaluation shows that FFCSB is not only more effective than CSB when the factors' effects are of different signs, but also more efficient in many cases even when the CSB assumption of all factor effect directions known *a priori* is satisfied since the benefit of ranking within each group outweigh the additional computational effort required by the resolution III design. The structure of the FFCSB procedure is provided in Figure 1.

Figure 1. Structure of FFCSB (from Sanchez, Wan and Lucas 2008)

The authors of this paper are all affiliated with the SEED Center for Data Farming at the Naval Postgraduate School. The mission of the SEED Center is: “Advance the collaborative development and use of simulation experiments and efficient designs to provide decision makers with timely insights on complex systems and operations.” SEED stands for simulation experiments and efficient designs, while data farming refers to the process of “growing” data via simulation. Links to papers, student theses, software, and other resources can be found at the SEED Center’s web pages (http://harvest.nps.edu). The scenarios examined in more than 50 student theses cover a range of application areas, including network enabled warfare, future forces, stability and support operations, homeland security, logistics, and more.

In this paper, we apply FFCSB to identify important factors in a Hierarchy model that drive the measure of performance of Project Duration. This Hierarchy model is representative of the prevalent structure in militaries and serves as a benchmark for comparisons of new organizational forms. The model is studied with factor ranges spanning two contrasting mission-environmental contexts: the Industrial Age and the 21st Century. This application appears in Chapter 4 of Oh’s (2007) master’s thesis.

2. EXPERIMENTATION TOOLS FOR ORGANIZATION THEORY

2.1. POW-ER Computational Experimentation Tool

These complex computer simulations of organizational behavior are developed in POW-ER—Projects, Organizations and Work for Edge Research—a virtual environment for computational modeling of C2 organizations and processes. POW-ER builds upon collaborative research and development between the Center for Edge Power at NPS and faculty at Stanford University. The organizational models are formulated from well-accepted organizational theory. The computation tool has been validated extensively and thoroughly via: "1) internal validation against micro-social science research findings and against observed micro-behaviors in real-world organizations, 2) external validation against the predictions of macro-theory and against the observed macro-experience of real-world organizations, and 3) model cross-docking experiments against the predictions of other computational models with the same input data sets" (Orr and Nissen 2006, p. 8; Levitt et al., 2005). The POW-ER environment uses agent-based simulation to emulate micro-behaviors (e.g., trust, learning, skill sets compatibility, skill competency, centralization) and discrete-event-simulation to emulate processes (e.g., meetings, exception occurrences, rework, process quality). Organizational performance is measured by quantitative metrics such as project duration, project risk, and project cost.

2.2. Computational Experimentation for Organizational Studies

Using the POW-ER environment, several researchers have conducted modeling, simulation and analysis of comparative performance of alternate C2 approaches, including different organization structures, work processes, technologies and personnel. Research and experimentation results have been published in a series of recent works. First, Nissen (2005) laid the fundamentals by defining the Hierarchy and Edge organization models from theory and comparing their performance in the Industrial Age and 21st Century mission contexts. Second, Orr and Nissen (2006) defined four more organization models and compared the performance of the six organizations in the Industrial Age and 21st Century mission contexts. Third, Gateau et al., (2007) articulated an organizational design space, using only three parameters of centralization, hierarchy and application experience to characterize organization models. Most recently, Mackinnon et al., (2007) calibrated and compared the impact of learning and forgetting micro-behaviors on the Hierarchy and Edge organizational models in the Industrial Age and 21st Century mission contexts

2.3. FFCSB: An Alternative Approach to Tackle the Same Question

The Hierarchy organization model is modeled by three sets of structural factors: (1) organization structure (2) communication structure (3) work structure (Nissen 2005, p. 11). The Industrial Age and 21st Century mission contexts are modeled by three manipulations of mission factors: (1) mission and environmental context, (2) network architecture and (3) professional competency (Nissen 2005, p. 14).

Researchers typically used full factorial experimental designs to explore organizational performance over different organizational structures and mission contexts. Nissen (2005) used a 2 organizations $\times$ 2 scenarios design, while Orr and Nissen (2006) used a larger 6 organizations $\times$ 2 scenarios $\times$ 4 manipulations design. Mackinnon et al., (2007) keeps simulation parameters constant between the Hierarchy and other organizations in order to isolate performance change due to learning and forgetting micro-behaviors only. Given that there are hundreds or thousands of factors in such complex organization models, it is computationally expensive or infeasible to conduct full factorial designs on individual factors. Instead, the design of experiments would use the six groups of factors listed above and change multiple factors within a group as one variation. Experimental results of organizational performance were analyzed over the entire organization's model changes and mission changes (Nissen 2005) or single block change (Orr and Nissen 2006, Mackinnon et al., 2007). Through analyzing the relative impact of each variation on individual organization performance, the researchers drew practical insights. For instance, Orr and Nissen inferred that: "professional competency improvements to the Hierarchy/Machine Bureaucracy can produce even more dramatic results in terms of agility as those associated with adopting the Edge organizational form. Hence, a change in professional competency can be substituted to a large degree for a change in organizational form. Unlike the substitution effects noted above for the network architecture manipulation, however, the converse does not hold for professional competency: changing organizational form does not compensate for a reversion to an efficiency-oriented organization and knowledge-flow approach" (2006, p. 16).

FFCSB offers an alternative approach to tackle the same question. It offers single factor resolution and allows researchers to probe questions such as: What are the most important factors, either organizational or mission, driving the measure of performance in an organizational model? Without group screening algorithms, it would have required an exorbitant amount of experimentation resources to conduct full factorial experiments to identify performance enhancement (or deterioration) due to single factors. FFCSB overcomes this limit by efficient division and experimentation of the entire factor space, and gradually limiting the scope of search for important factors. Through group screening of singular factors, FFCSB can shed light on significant individual factors within each structural or mission factor block that have the most impact on the outcome of interest.

3. MODEL DESCRIPTION & SIGNIFICANCE

3.1. Hierarchy Organizational Model

Figure 2 is a screen-capture of the Hierarchy model in the POW-ER environment. The figure illustrates the personnel hierarchy and mission structure in the Hierarchy model. Personnel are grouped and communicate over a 3-tier command chain, which emulates the Command, Coordination and Operations levels in a Joint Task Force Hierarchy (Nissen 2005). There are four tasks executed sequentially via two phases. Tasks are linked to each other and to project milestones. Tasks can flow completed work down the chain, or flow rework (additional work to rectify earlier mistakes). Personnel are linked to work on meetings and tasks. Operations level personnel act directly on tasks, while

Command and Coordination level personnel act directly upon their specialized tasks while indirectly supporting operations tasks.

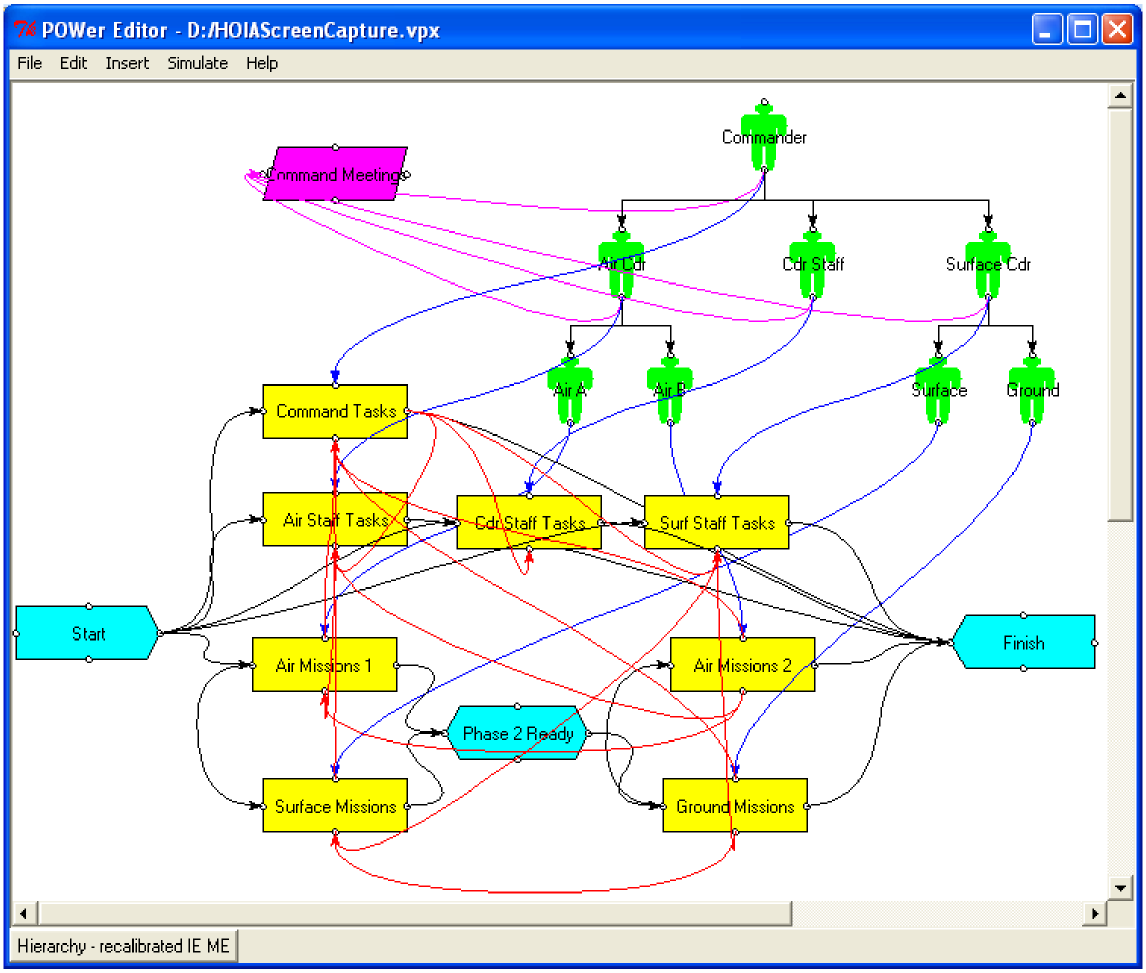

Figure 2. Hierarchy Organizational Model in POW-ER (from Oh, 2007)

3.2. Measure of Performance: Project Duration

Earlier quoted works compared organizational performances using seven measures of performance (MOPs): duration, cost, project risk, maximum backlog, work volume, rework volume and coordination volume. This FFCSB application focuses on the first MOP of interest: (Project) Duration. Duration is defined as "the predicted time to perform a project, in working days, which includes both direct and indirect (i.e., coordination, rework and decision latency) work" (Orr and Nissen, 2006).

3.3. Factor Exploration Space

Table 1 lists the factors identified in the Hierarchy model for the FFCSB application, conducted at the International Data Farming Workshop 15 in Singapore in November 2007. A team of four international data-farming enthusiasts collaborated on the simulation and analysis of this exploration for a week. In order to keep within the computation resources and time constraints for this section, the entire factor space was divided into three subspaces for separate FFCSB exploration. Hence, three smaller and faster explorations were conducted instead of one big exploration. The division of the factor space followed the three manipulations of mission context factors: (1) mission and environmental context, (2) network architecture and (3) professional competency. In addition, the three sets of structural factors: (1) organization structure (2) communication structure and (3) work structure were subsumed under these factor subspaces. This division of factor space was intended to mirror that in the literature as closely as possible, but was not exact. The factor ranges of exploration were derived from the default values of the Hierarchy model in the contrasting mission contexts of Industrial Age and 21st Century (see Appendix for details). In lieu of requesting SMEs to specify thresholds, we selected these based on the range of effects observed in some preliminary experiments.

Mission & Environment	Network Architecture	Professional Competency
(Project) Function Exception Probability	(Project) Priority	(Project) Team Experience
(Project) Project Exception Probability	(Project) Length Of Work-day	(Personnel) Culture
(Task) Effort	(Project) Length Of Work-week	(Personnel) Role
(Task) Learning Days	(Project) Centralization	(Personnel) Application Experience
(Task) Priority	(Project) Matrix-strength	(Personnel) Cultural Experience
(Task) Requirement Complexity	(Project) Communication Probability	(Personnel) Skill Ratings
(Task) Solution Complexity	(Project) Noise Probability	
(Task) Uncertainty	(Project) Instance Exception Probability	
(Personnel) Full Time Equivalent	(Meeting) Priority	
(Personnel-Task) Allocation	(Meeting) Duration	
(Task-Task) Successor	(Personnel-Meeting) Allocation	
	(Task-Task) Rework Strength	

Table 1. Factor Space for Exploration of Hierarchy Model

FFCSB was also applied to the Hierarchy model with this entire factor space in one exploration. However, this single exploration took weeks to run, without yielding results. The sequential nature of FFCSB meant that the experiments could not be parallelized. There were unusually long simulation times of the Hierarchy model, possibly due to combinations of factors that were either unreasonable or stressed the model too much.

3.4. Expert Opinion on Significant Factors

Among the factors identified for exploration, subject matter experts (SMEs) identified the following as important before the experiments began.

1. Mission & Environment
   a. (Personnel) Full Time Equivalent
   b. (Task) Effort
2. Professional Competency
   a. (Personnel) Application Experience
   b. (Personnel) Skill Ratings

3.5. FFCSB Findings On Significant Factors

Tables 2 and 3 summarize the FFCSB findings of important factors in the Hierarchy model that impact Project Duration most. There were no factors classified as important in the Network Architecture factor subspace.

Object	Attribute	Factor Effect on Duration
Mission	Project Exception Probability	+
Surface Missions	Effort	+
Surface Missions	Solution Complexity	+
Ground Missions	Effort	+
Ground Missions	Requirement Complexity	+
Ground Missions	Solution Complexity	+

Table 2. Important Factors in Mission & Environment Factor Subspace

Object	Attribute	Factor Effect on Duration
Mission	Team Experience	+
Air A (Personnel)	Skill Ratings	-
Ground (Personnel)	Skill Ratings	-

Table 3. Important Factors in Professional Competency Factor Subspace

4. DISCUSSION

Before we discuss the results, a few general comments are in order. First, all factors effects correspond to the impact on the MOP of changing that factor from its lowest to its highest value. Widening the range for a factor deemed unimportant in our experiment might make it show up as important, while narrowing the range for a factor deemed important in our experiment might make it drop out. Similarly, an analyst using more stringent thresholds than ours to define what constitutes an important factor would tend to see fewer factors identified as important, while an analyst using a less stringent threshold would tend to see more. The goal of this study is not to provide a definitive assessment of how the Hierarchy model behaves in general, but rather to show that a large-scale screening experiment can provide a rich set of insights into the model's behavior. As well as a means of confirming or refuting specific hypotheses developed a priori, this can be used to focus discussion, generate additional hypotheses, or explore how robust the organizational performance is to variations in, say, the environment or the task.

4.1. Comparison of SME Opinion and FFCSB Results

In the first factor subspace of Mission & Environment, SMEs identified the factors of Full Time Equivalent (FTE) and Effort as important. FTE measures the equivalent of manpower resources available and Task Effort quantifies the time effort requirement of the task. Contrary to expert opinion, FFCSB does not classify any FTE factors as important over the factor range of exploration. Thus, FTE is not as important as the other factors in this subspace in impacting the Project Duration. This is an interesting finding, particular since FTEs were varied over a wide range (from one-half to twice the default number for each personnel category). The implications here are that the organizational performance is robust to the loss of FTE in any single personnel category, and that adding more manpower to any single group also has relatively little impact on project duration. Further experimentation could be used to confirm these results, or to estimate the net impact of simultaneous FTE changes in two or more teams.

In line with expert opinion, FFCSB classifies Effort factors as important, but of the eight possible missions, only those for Surface Missions and Ground Missions are flagged. Critical path analysis of the Hierarchy model explains why factors associated with only these two missions showed up consistently as important. The red bars in Figure 3 depict the critical path of the project simulated in the Hierarchy model. Following the red bars, the Air Missions 1, Surface Missions and Ground Missions are on the critical path. Of these three missions, the Surface Missions and Ground Missions have minimum float, i.e., there is no allowance for shifting these missions in time. Hence, these two missions are crucial to the MOP of Project Duration. Besides the Task Effort factor, FFCSB also classified the Solution Complexity factors of the Surface and Ground Missions as important, as well as the Requirements Complexity of the Ground Missions. Thus, FFCSB has further quantified expert opinion by flagging only factors associated with missions on the critical path with specific characteristics.

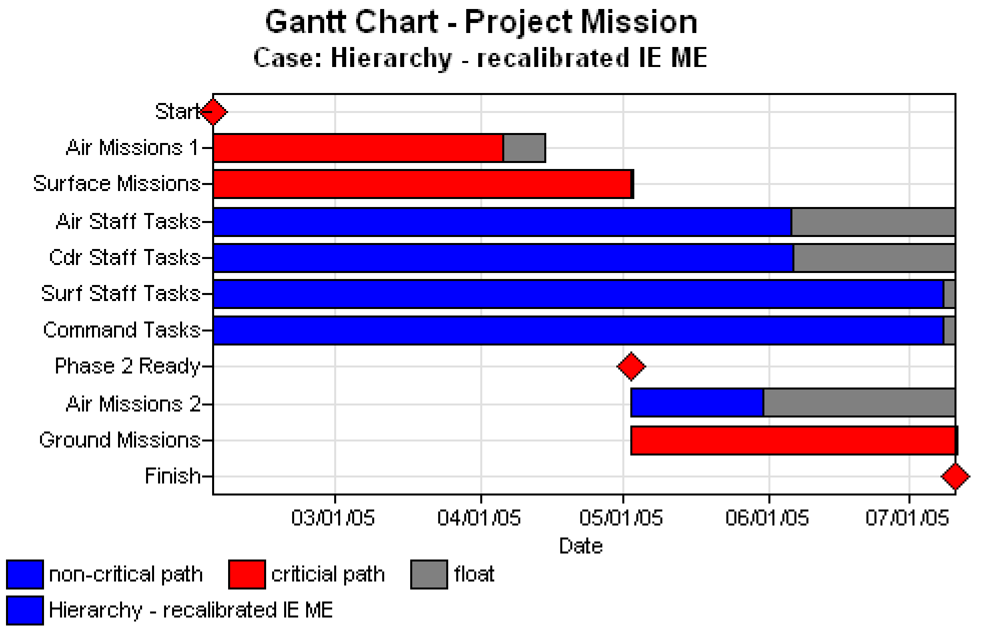

Figure 3. Critical Path Analysis of Hierarchy model shows Air Missions 1, Surface Missions and Ground Missions on Critical Path (Best viewed in color)

In addition, FFCSB classifies the global factor of Project Exception Probability (PEP) as important. PEP is the probability that a subtask will fail and generate rework for failure dependent tasks. This factor is significant for the Hierarchy model that is characterized by sequential and interdependent tasks and hence, suffers a longer Project Duration in the event of increased PEP.

In the second factor subspace of Network Architecture, there are no factors classified as important. This finding is in agreement with SMEs, who did not expect any important factors in this subspace. A set of (relatively computationally expensive) resolution V fractional factorial design (allowing the estimation of both main effects and two-way interactions) was used to verify the factor coefficients in this factor group. (Sanchez and Sanchez (2005) provide a simple method for generating resolution V fractional factorials for very large numbers of factors; code in the form of an executable jar file is available at the SEED Center for Data Farming web pages.) The results confirmed that the factor coefficients were relatively small in magnitude and hence, practically insignificant. We remark that Network Architecture is the area where the majority of the money and effort have gone in pursuit of developing net-centric or net-enabled forces. It is interesting that both our SMEs and our FFCSB results agree that Network Architecture is unimportant. These results suggest that, at least for Hierarchical C2 structures such as the one we study, a shift in focus to examine the mission environments and individual skill levels would be beneficial.

In the third factor subspace of Professional Competency, experts identified Skill Ratings and Application Experience factors as important. FFCSB classified the Skill Ratings of the Air A and Ground personnel as important, but not that of the Surface personnel. These three groups of personnel are operations personnel and directly responsible for the missions on the critical path. The contrast between the three missions is that the Surface Missions require a considerably longer effort of 21 months versus that of the Ground Missions (6.5 months) and Air Missions 1 (11 months). These findings suggest that Skill Levels may be more critical for missions that lie on the critical path and have relatively shorter Effort requirements. FFCSB did not classify Application Experience as important.

However, interestingly, FFCSB classified Team Experience as important and positively related to the MOP. Team Experience quantifies the degree of familiarity that team members have in working with one another as a team. In other words, this finding suggests that more team experience leads to longer Project Duration in the Hierarchy model. This result seems counter-intuitive. In fact, in two workshops subsequent workshops where participants were shown the factor categories in Table 1 and asked to identify factors they felt were important, Team Experience was chosen as a way to decrease project duration time! Yet this seemingly counter-intuitive finding may have been observed in earlier research and experimentation. Ramsey and Levitt (2005) summarized high level findings from Horii, Jin and Levitt's "Modeling and Analyzing Cultural Influences on Team Performance through Virtual Experiments" (2004) on the impact of cultural differences in project teams: "Japanese-style organizations were more effective, with either US or Japanese agents, at performing tasks with high interdependence when the team experience of members was low." The Hierarchy model studied in this application shares common characteristics of centralized authority, high formalization, and multiple hierarchies with the Japanese-style organization modeled in Horii, Jin and Levitt (2004, pp. 3). In addition, these experiments had used the MOPs of Project Duration and Quality Risk to quantify team performance, while this FFCSB application only used Project Duration. Hence, there is common ground to compare the similarity of both findings. Had the original intuition on Team Experience been applied with conventional screening algorithms, this factor could have distorted screening findings.

Lastly, there were two general observations of interest. First, there were more important factors associated with the Operations layer of the JTF structure than the other layers. Recall that the Hierarchy model has a 3-tier command chain that models the Command, Coordination and Operations layers in a JTF. Second, there were more uncontrollable or difficult to control factors (e.g., Project Exception Probability, Task Requirement Complexity, Task Solution Complexity and Team Experience) than controllable or easy to control factors (e.g., Skill Ratings.)

4.2. Choice of Screening Method

The important factor classification and observations are meant to provide direction for researchers in future work and optimize their experimentation budget on truly important factors. This first-case FFCSB application on a real-world simulation model has produced results that are coherent with critical path analysis and that agree with earlier research on similar models. Hence, it is an encouraging sign that FFCSB can serve as a complementary tool to better understand complex simulation models. Of course, these findings are preliminary and apply to a specific hierarchical C2 structure: care should be taken in drawing general conclusions.

FFCSB is not the only potential experimental design that can be applied to complex simulation models. Other experimental designs are also suitable for these types of applications, and further methodological work is currently underway. A variant called FFCSBX is useful for categorizing main effects even in the presence of two-way interactions (Sanchez et al., 2008). Another screening approach uses sequential fractional factorial designs that are typically more efficient than a single-stage fractional factorial design (Shen and Wan 2005). A hybrid approach allows the analyst to estimate factor effects (rather than simply classify factors as important or unimportant) at the completion of the experiment (Wan et al., 2008). In addition, the new DOE-based algorithm of Chang et al. (2007), called Stochastic Trust Region Gradient-Free Method (STRONG), for solving large-scale simulation optimization problems, appears particularly promising because it is easy to automate and yet has provably reliable asymptotic performance. Regardless of the screening procedure used, the analyst may wish to follow up with further experiments that examine those factors deemed important in more detail.

5. CONCLUDING REMARKS

In this paper, we illustrate how an efficient experimental design approach can support current research in Computation Organization Theory. The FFCSB application produced many delightful surprises. Part of the important factor classification was in line with expert opinion and part of it ran contrary to expectations. There were new findings of important factors that were justified by critical path analysis and in agreement with earlier research and experimentation. Overall, this particular FFCSB application has confirmed expert opinion, flagged out new important factors and produced some interesting hypothesis, all for further exploration.

There are limitations to the FFCSB application to any model. FFCSB assumes a main effects model and interactions can distort the accuracy of factor classification. The nature of the response variance (homogeneous or heterogeneous) and its magnitude are unknown. Both model characteristics can have bearings on the FFCSB findings and accuracy guarantees. Particular to the Hierarchy model, the observations of this FFCSB exploration are unique to the factor space organization and ranges of exploration. Hence, the findings are not conclusive of the Hierarchy model. The important factor classification and observations are meant to provide direction for researchers in future work and optimize their experimentation budget on truly important factors. This first-case FFCSB application on a real-world simulation model has produced results that are coherent with critical path analysis and that agree with earlier research on similar models. Hence, it is an encouraging sign that FFCSB can serve as a complementary tool to better understand complex simulation models.

Continued exploration of the Hierarchy model with different factor space organization and factor ranges would form a good sensitivity analysis study of the FFCSB application on the model. Exploring an Edge organization model would form an interesting study in itself, and allow for meaningful contrasts between the competing organizational forms.

The benefits of being able to easily perform a screening experiment on a complex organizational model cannot be overstated. In the absence of this capability, an analyst must either limit themselves to a small number of factors to investigate, or make changes to a large number of factors simultaneously to come up with a small number of organizational forms, settings, or task types to investigate. We remark that the POW-ER model and its predecessor, VDT (Virtual Design Team Research Group, 2006) have been successfully used in practice for over a decade. Although this model that has been "validated" by a history of successful applications in the field, it is nonetheless difficult for experts to fully grasp the complex interplay of the complete set of potential factors. This is particularly important in command and control research, as we seek—not to model existing organizations and organizational structures—but to define new ones that will be effective for our military transformation.

Screening experiments also offer opportunities to validate a model for a particular use. For example, if results contradict SME opinion and, after further discussion or field experiments, the model results are shown to be inaccurate, the model should be modified. Controversial results from a screening experiment may, in fact, help identify alternatives that merit testing in the field. In the long run, this cycle of model-test-model will lead to models that provide better representations of reality, as well as a better understanding of the model's behavior, strengths, and limitations.

In summary, there are efficient experimental designs and screening approaches that are easy to implement, require fewer assumptions than conventional experimental design methods, and yet can provide analysts with better insights when the experiments are complete. These can substantially reduce the computational requirement for military leadership to identify optimal factor combinations, and lead to a much broader and deeper understanding of the system. This will facilitate the decision making process dramatically.

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APPENDIX

Table 4 lists the factors identified in the Hierarchy model for FFCSB application and their range of exploration.

Object	Factor	Organizational Structure		FFCSB Exploration	
		Industrial Age Hierarchy	21st Century Hierarchy	Low value	High value
Project	Priority	Medium	Medium	Low	High
	Work-day	480	480	360	600
	Work-week	2400	2400	1440	3600
	Team Experience	Low	Low	Low	Medium
	Centralization	High	High	Medium	High
	Formalization	High	High	Medium	High
	Matrix Strength	Low	Low	Low	Medium
	Communication Probability	0.1	0.1	0.05	0.2
	Noise Probability	0.3	0.3	0.01	0.6
	Functional Exception Probability	0.1	0.2	0.05	0.4
	Project Exception Probability	0.1	0.2	0.05	0.4
	Instance Exception Probability	0	0	0.01	0.4
Meeting	Priority	High	High	Medium	High
	Duration	2 hours	2 hours	0.5 hours	4 hours
Personnel	Culture	Generic	Generic	American	Japanese
	Role	(Various)	(Same)	PM	ST
	Application Experience	Medium	Low	Low	Medium
	Cultural Experience	Medium	Medium	Low	High
	Full Time Equivalent	(Various)	(Same)	0.5 * Default	2 * Default
	Skill Ratings	Medium	Medium	Low	High

Table 4. Factors & Ranges in Hierarchy Model for FFCSB Application

Object	Factor	Organizational Structure		FFCSB Exploration	
		Industrial Age Hierarchy	**21st Century Hierarchy**	**Low value**	High value
Task	Effort	(Various)	(Same)	0.5 * Default	2 * Default
	Learning Days	0	0	0	90
	Priority	Medium	Medium	Low	High
	Requirement Complexity	Medium	High	Medium	High
	Solution Complexity	Medium	High	Medium	High
	Uncertainty	Medium	High	Medium	High
Meeting Assignment		0.1-1.0		0.1	1.0
Task Assignment	Allocation	0.9-1.0	1.0	0.7	1.0
Successor	Time Lag	0	0	0.0 pct-complete	0.5 pct-complete
Rework	Strength	(Various) 0.15,0.3,1.0	0.1	0.15	0.3

Table 4 (contd). Factors & Ranges in Hierarchy Model for FFCSB Application

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