2009-03

Team 5: Sequential Screening for Organizational Performance

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Abstract

Fractional Factorial Controlled Sequential Bifurcation (FFCSB) is a newly proposed two-phase screening procedure for large-scale simulation experiments. Sequential screening algorithms inform the decision maker of critical factors in their simulation models and optimize the use of computation resources in studying only critical factors.

At IDFW15, FFCSB is applied to the Hierarchy organizational model, which serves as a benchmark to compare innovative Command and Control (C2) structures for enabling more effective warfare. The model is developed in Projects, Organizations and Work for Edge Research, which crystallizes two decades of collaborative research between the Naval Postgraduate School (NPS) and Stanford University.

Motivation

Everyday, organizations use software simulations to make better decisions. Software simulations of real world systems are often large and rich with many parameters potentially affecting final outcomes. Faced with a multitude of parameters, decision makers may not know or may lose sight of the few truly critical factors. Thus, screening algorithms are essential in order to identify the factors that most impact outcome measures. This enables experimenters to better utilize their resources by focusing on truly important factors.

Fractional Factorial Controlled Sequential Bifurcation (FFCSB)

FFCSB is a newly proposed two-phase screening procedure for large-scale simulation experiments (Sanchez, Wan and Lucas, 2005.) FFCSB comprises two stages: (1) a fractional factorial (FF) pre-screening phase to sort factors by the direction of their effects (whether an increase in factor leads to a positive or negative change in the measure of performance) and (2) a controlled sequential bifurcation (CSB) to conduct sequential experimentation with accuracy guarantees.

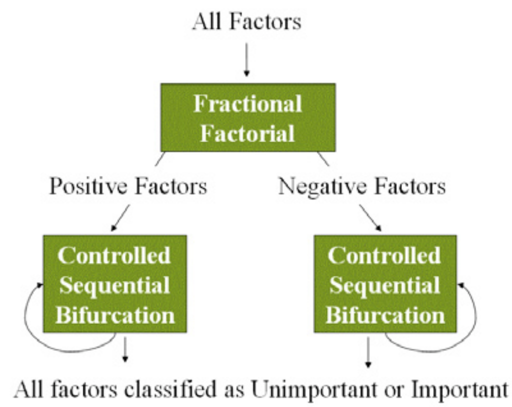

Figure 1: Conceptual Flow of FFCSB

FFCSB offers several enhancements over conventional screening algorithms. First, FFCSB dramatically reduces the need for *a priori* knowledge on the direction of factor effects, which is often a condition for optimal performance of conventional algorithms and has proven difficult to meet. FFCSB also does not require *a priori* knowledge of the number of experiments required for factor classification. It conducts sufficient experiments to complete classification. Second, FFCSB scales well for large scale models with thousands of factors. Third, FFCSB provides accuracy guarantees in its factor classification. Fourth, FFCSB provides a savings in computation.

Hierarchy Organizational Model in POW-ER

At IDFW15, FFCSB is applied to the Hierarchy organizational model developed by the Center for Edge Power (CEP) at NPS and Stanford University. CEP studies innovative C2 structures to enable more powerful warfare. The Hierarchy model is developed in POW-ER—Projects, Organizations and Work for Edge Research—a virtual environment for computational modeling of C2 organizations and processes. This computation tool crystallizes two decades of collaborative research between NPS and Stanford University. The tool is based upon sound research in organizational studies and has been validated extensively and thoroughly (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, project cost.

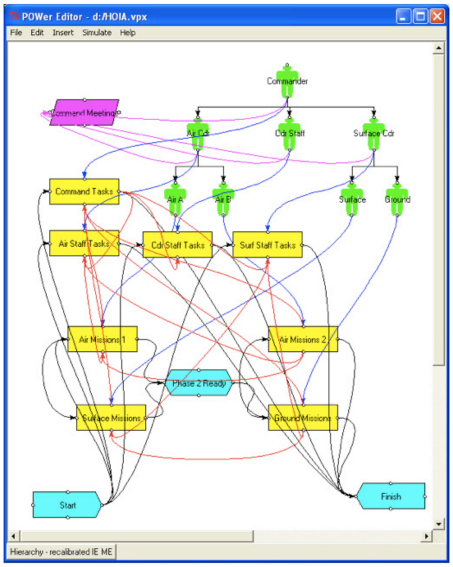

Figure 2: Hierarchy Organization Model in POW-ER

The Hierarchy model is modeled by three sets of structural factors: (1) organization structure (2) communication structure (3) work structure (Nissen 2005 p. 11.) The model is simulated in two contrasting mission contexts: Industrial Age and 21st Century. The 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.)

In computational experiments on the Hierarchy and other organizational models, the researchers typically varied one factor group (i.e., multiple factors) at a time, and record multiple Measures of Performances (MOPs) associated with each factor group change. The various organization models are then compared using these results and changes in performance are justified by the experimental manipulations.

FFCSB extends CEP's suite of tools for computational experimentation. Through smart and efficient designs of experiments, FFCSB identifies single critical factors that most impact the single MOP of Project Duration.

Methodology of Applying FFCSB on Hierarchy Model

Subject matter experts selected Project Duration as the MOP of interest for FFCSB application. They also identified 114 factors of interest, with associated 2-level factor ranges for exploration.

Working within the computation and time constraints of IDFW15, the team refined the factor ranges to smaller ranges of interests and divided the entire factor space into three smaller subspaces. The factor space is shown in the Table 1. These factors categories are intended to mirror those used in prior experimentation (Gateau et al., 2007, pp. 7-8) but may not be exact.

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

Table 1: Factor Spaces of Exploration for the Hierarchy Model

Results of FFCSB Exploration

The following tables (2-3) summarize the FFCSB findings of important factors in the Hierarchy model that most impact Project Duration. There were no factors classified as important in the Network Architecture factor subspace.

Object	Attribute	Effect Direction
Mission	Project Exception Probability	+
Surface Msn	Effort	+
Surface Msn	Solution Complexity	+
Ground Msn	Effort	+
Ground Msn	Requirement Complexity	+
Ground Msn	Solution Complexity	+

Table 2: Important Factors in Mission & Environment Factor Subspace

Object	Attribute	Effect Direction
Mission	Team Experience	+
Air A	Air Skill Ratings	-
Ground	Ground Skill Ratings	-

Table 3: Important Factors in Professional Competency Factor Subspace

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 did not classify any FTE factors as important over the factor range of exploration. Therein lies our first surprise: FTE is not as important as the other factors in this subspace in impacting the Project Duration. In line with expert opinion, FFCSB classified Effort factors as important, but only for Surface Missions and Ground Missions out of all eight missions in the Hierarchy model. Critical path analysis of the Hierarchy model explains why factors associated with only these two missions showed up consistently as important.

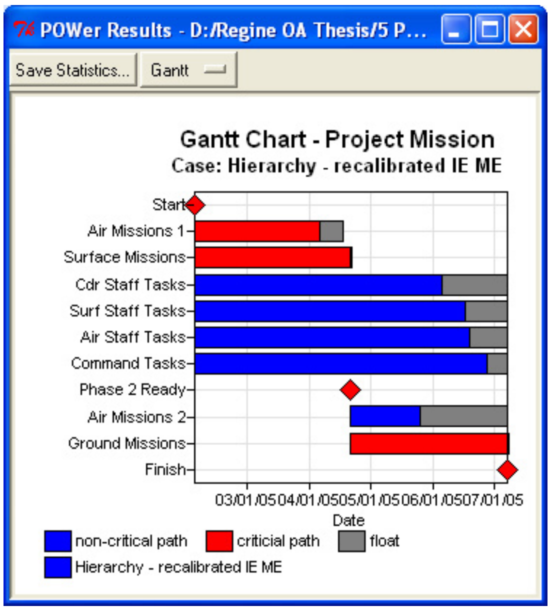

Figure 3: Critical Path Analysis of Hierarchy model shows Air Missions 1, Surface, and Ground Missions on Critical Path

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. This is our second surprise: FFCSB has further quantified expert opinion by flagging those factors associated with missions on the critical path only and with specific characteristics.

In addition, FFCSB classified 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.

Our third surprise is: In the second factor subspace of Network Architecture, there are no factors classified as important for the particular factor ranges explored. 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 Factorials design was used to verify the factor coefficients in this factor group. The results confirmed that the factor coefficients were relatively small in magnitude and hence, practically insignificant.

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 responsible for the missions on the critical path. The contrast between the three missions is that the Surface mission requires considerably more effort of 21 months versus that of the Air Missions 1 (11 months) and Ground Missions (6.5 months). These findings suggest that Skill Ratings 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.

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 is our fourth surprise. This 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 interesting observations. The Hierarchy model has a 3-tier command chain that models the Command, Coordination and Operations layers in a Joint Task Force. There were more important factors associated with the Operations layer than the other layers. 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.)

Way Ahead

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 could 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.

The team is greatly encouraged by the findings of the first-case application of FFCSB on a real world simulation model. There were interesting findings and many delightful surprises. Initially, some findings appeared counter-intuitive to the data-farmers but were later justified through critical path analysis and through comparison 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.

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