CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

A Trajectory for Validating Computational Emulation Models of Organizations

By

Jan Thomsen, Raymond Levitt, John Kunz,
Clifford Nass, and Douglas Fridsma

CIFE Technical Report #153
1999; November 2003

STANFORD UNIVERSITY

If you would like to contact the authors, please write to:

c/o CIFE, Civil and Environmental Engineering Dept.,
Stanford University
Terman Engineering Center
Mail Code: 4020
Stanford, CA 94305-4020

Published in the *Journal of Computational & Mathematical Organization Theory, 5, (4),* 1999, pp. 385-401

A Trajectory for Validating Computational Emulation Models of Organizations[1]

JAN THOMSEN, RAYMOND E. LEVITT, JOHN C. KUNZ
Construction Engineering and Management Program,
Department of Civil and Environmental Engineering,
Stanford University, Stanford, CA 94305-4020

CLIFFORD I. NASS
Department of Communication,
Stanford University, Stanford, CA 94305-2050

DOUGLAS B. FRIDSMA
Palo Alto Veterans Administration Health Care System
Palo Alto, CA 94306
Stanford Medical Informatics
Stanford University, Stanford, CA 94305-5479

Abstract

Validation of complex simulation models is a challenging problem in computational organization theory research. In this paper, we describe a validation strategy suitable for emulation simulation systems, and show how a comprehensive validation consists of a sequence of steps that evaluate different aspects of a computational organizational simulation model. We demonstrate how this strategy can be applied to the evaluation of the Virtual Team Alliance (VTA), an emulation simulation system designed to guide managers charged with organizational change. VTA required a "trajectory" of successive validation experiments, before managers were willing to follow the recommendations of VTA. Ultimately, we believe this validation approach can be applied to a wide range of different simulation systems, and will make identification of the strengths and weaknesses of organizational simulations easier.

Key Words and Phrases: Contingency Theory, Computational Organizational Simulation Models, Information Processing, Intervention, Organizational Design, Validation.

1. The Need for Systematic Validation of Computational Models

Validation of complex computational organizational models is a challenging problem that has received considerable attention in the Computational Organizational Science (COS) literature (e.g., Baligh *et al*., 1994; Burton and Obel, 1995; Carley, 1997, Kleindorfer *et al*., 1998; Simon, 1998). One of the most difficult validation problems facing COS

[1] Jan Thomsen, Raymond Levitt, John Kunz and Clifford Nass were supported by the National Science Foundation, Transformations to Quality Organizations program, Grant SBR- 9422389. Douglas Fridsma is supported by the Veteran's Administration Fellowship in Medical Informatics at the Palo Alto Healthcare Systems. The opinions expressed in this paper are those of the authors, and are not necessarily those of the funding agencies.

researchers is the validation of emulation-based models that provide detailed, practical advice to practitioners on organizational design issues (Jin and Levitt, 1996; Carley, 1997; Friedman and Wyatt, 1997; Fridsma, 1998; Oreskes *et al.*, 1994). In this paper, we propose a validation framework that breaks the process of evaluation into manageable subtasks, and then builds a case for the validity of the simulation model based on the results of these subtasks. We believe our validation framework is suitable to validate diverse models, and show how this approach to validation has been used in the Virtual Team Alliance (VTA) (Thomsen, 1998) an emulation-based model that links goal incongruency among organizational members to the broader information processing behavior of the organization. VTA is an extension of the Virtual Design Team research, and represents the third version of the Virtual Design Team (Cohen, 1992; Christiansen, 1993; Jin and Levitt, 1996) simulation system.

2. The Importance of Simulation Models to the Understanding of Organizations

Organization theory is a broad area of research that investigates both aggregate behaviors between large organizations as well as smaller groups and individuals interacting within organizations. The breadth of research within computational organization theory has made it difficult to find a validation strategy that unifies the approaches used in computational organization theory and the different frames-of-references that exist within simulation models (Carley, 1995, Simon, 1996). We believe that understanding the place that simulation holds in theory development is important to understanding how simulation models should be validated.

To understand better the role of validation in organization theory, we divide organizational theory into four principle areas of investigation—macro-theories, micro-theories, macro-experience and micro-experience. Macro-theories describe the large-scale behaviors within and among large groups and organizations (Galbraith, 1973; 1977; Tushman and Nadler, 1977). Micro-theories explain how agent behavior is affected by organizations (e.g., Cyert and March, 1992; Simon, 1997). Macro-theories might be described as the “physics” of an organization, while micro-theories describe the “chemistry” of the organization.

In both macro- and micro- theory developments, researchers confirm their hypotheses by observing macro-experiences and micro-experiences. For example, a researcher might compare two organizations and their response to environmental uncertainty or observe how agents within an organization function in response to goal incongruency. However, few researchers relate micro-theories to macro-theories or micro-experiences (the behavior of individuals in the organization) to macro-experiences (the aggregate behavior of organizations). Often the way in which agent behavior aggregate to form the emergent behavior of an organization is not always intuitive. Figure 1 describes the relationship between micro and macro theories and experiences.

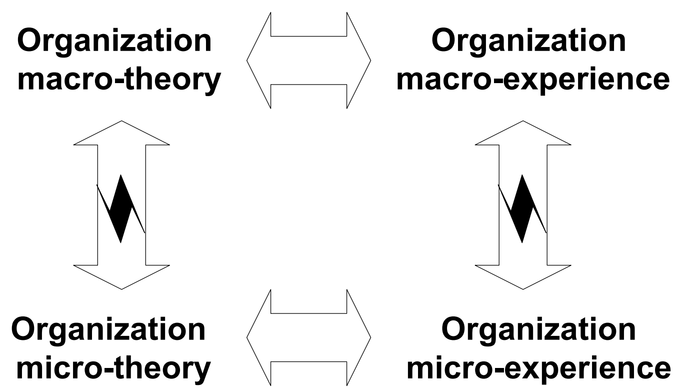

Figure 1: Traditional Organizational Research. In traditional organizational research, theories describing the aggregate behavior of organizations (macro-theories) are compared to observations of organizational behavior (macro-experience). Likewise, theories of agent interactions (micro-theory) are compared to the experience of agents in organization (micro-experience). Because of the complexity of both organization theory and observation, relating macro theories and macro-experiences to micro-theory and micro-experience is difficult.

Simulation systems used in computational organization theory however, are intermediate representations that relate micro-theories and micro-behaviors to emergent macro-theories and macro-behavior. Within computational-organization theory, there is a spectrum of different simulation and research emphases. Certain computational models use highly stylized problems that illustrate conceptual or theoretic extensions to organization theory (Carley and Svoboda, 1996; Carley and Lin, 1997; Masuch and P. LaPotin, 1989). Other models emphasize emulation-based simulation models that are based on real organizational data and can give practitioners advice about their organization (Christensen *et al*., 1996; 1999; Cyert and March, 1992; Thomsen, 1998; Thomsen and Kwon, 1996). Both types of simulation models sit between the theory they encode and the real-world observations they assist us in understanding. The relationships among theory, simulation models, and organization experience are shown in Figure 2.

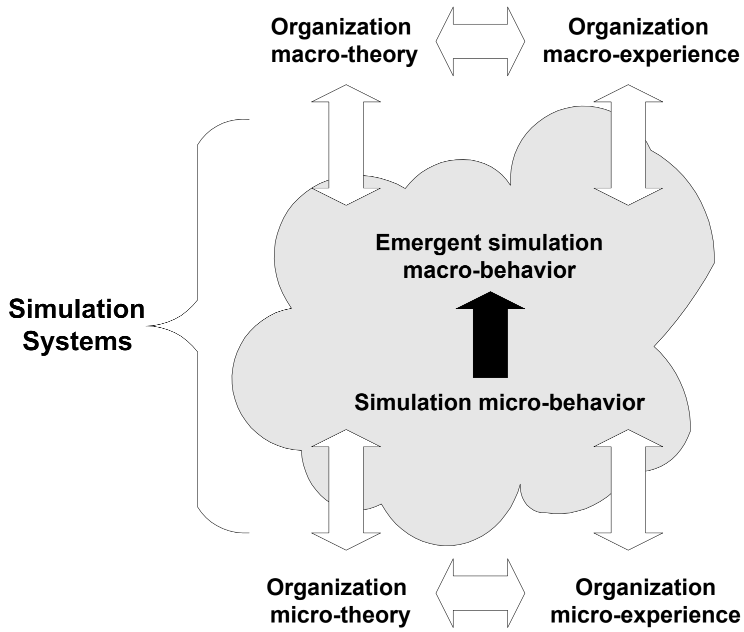

Figure 2: Simulation systems bridge the gap between theory and experience at a micro and macro level. Before simulation tools, it has not been possible to rigorously relate micro and macro organization theories or experiences. Simulation of micro-behaviors and their interaction generates macro-predictions that can be tested against both predictions of macro theory and macro organization experience.

Because not all simulation models are created for the same purpose, we believe that validation should be tailored to reflect the design intention of the simulation model (Burton and Obel, 1995b; Kleindorfer *et al.*, 1998). In addition, Law and Kelton (1991) argue that validation of emulation models is a matter not of valid or invalid, but rather of degree. This suggests that validation of simulation systems should be an iterative, multi-faceted approach in which each successive validation experiments builds confidence in the validity of the simulation model. Our strategy for validation follows an iterative, multi-faceted approach to "building a case" for simulation validity.

3. A Trajectory of Validation Strategies

Figure 3 below shows our proposed validation trajectory. Even though the validation steps are autonomous, there is a conjunctive relationship among them. Each successive validation step adds confidence that users have in the emulation model.

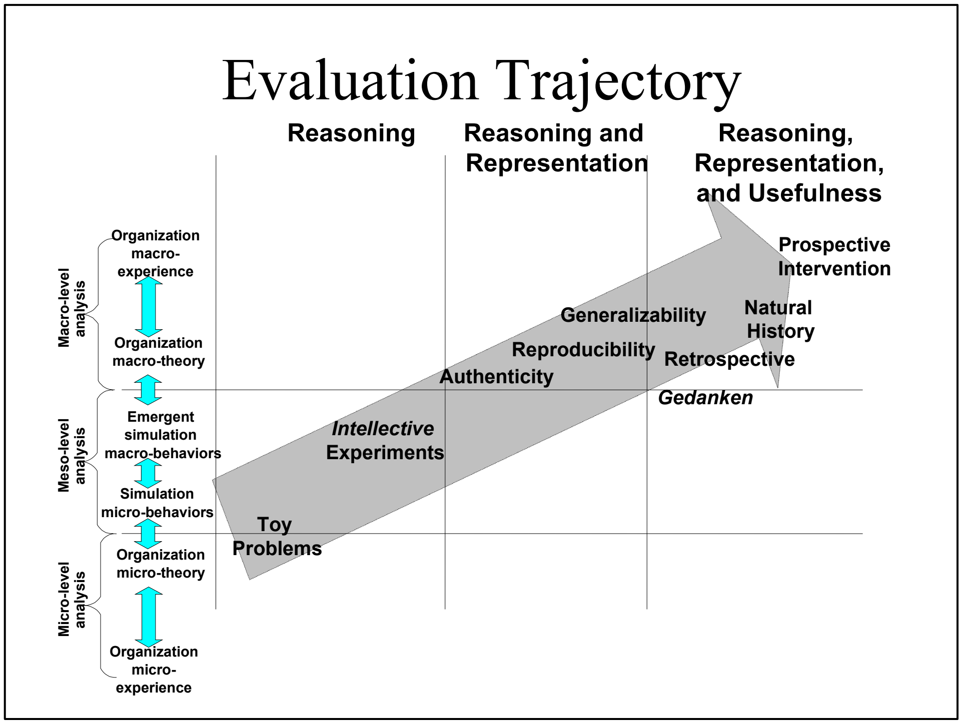

Figure 3: A Validation Trajectory. This figure describes the interactions among micro, meso, and macro level analysis of organizations. Validation of *reasoning* focuses on the relationship among micro-theory, micro-behavior, and macro-behaviors in the simulation model. *Representation and Reasoning* compares simulation models to experience on both a micro (agent) and macro (organization) level. Finally, validation of *Reasoning, Representation and Usefulness* determines the value of theory—encoded in the simulation model—on the organization experience.

In our validation trajectory, we link the micro-level of theory and experience to the macro-level of theory and experiences with a meso-level of simulation that includes simulation micro-behavior and emergent simulation macro-behaviors. Simulation is a tool to bridge the gap between micro- and macro- theory and experience.

Further, we describe three essential components that require validation. First, the reasoning assumptions of the simulation must be validated. For example, researchers might describe how individuals within an organization communicate, how uncertainty in work activities generates communication, or how attributes of work activities contribute to uncertainty. These micro-theories relate to an observable micro-behavior and ultimately to the behaviors observed in the simulation For simulation systems in which theory generation in hypothetical or stylized organizations is most important, further evaluation may not be necessary.

For emulation systems, two further validation steps are necessary—validation of representation, and finally, validation usefulness. Each of these components builds on the validation work of previous experiments.

Validation of representation evaluates how well the simulation system can capture and simulate the important features being studied. For example, in a simulation system that examines goal incongruency, it is important that the method of capturing agent goal incongruency in real-world situation is reliable, reproducible, and generalizable to different settings.

Finally, the value of an emulation-based simulation system is in the advice that it can give, and the ability of the simulation to take axiomatic micro-behaviors and generate useful macro-level descriptions to guide organizational design. These can be retrospective, predictive (*gedanken* experiments) or prospective, each with increasing confidence and value to the user. As project managers gain confidence in the ability of the computational model to provide useful assistance through multiple experiments, they will begin to commit real resources in their organization in response to simulation results.

In the following sections, we describe the principal components of our validation approach and illustrate how this approach was used to validate an emulation-based simulation model called the Virtual Team Alliance (VTA) on the Lockheed Launch Vehicle Project (Thomsen and Kwon, 1996), the Norne Subsea Satellite Design Project (Thomsen *et al*, 1998a), and the A2100 Pyrovalve Development Project (Thomsen *et al*, 1998c). In VTA, we explored the interaction between the organizational contingency macro-theories (Thompson, 1967, Galbraith, 1973) and agency and goal incongruency micro-theories (Thomsen, 1998) by examining individual activities and actors, and treating organizational behavior and performance as emergent from the actions of and interactions among actors. This was an ideal setting in which to examine how simulation can bridge the gap between micro- and macro-theories, and one in which our validation framework was well suited.

3.1 Validation of Reasoning using Toy Problems and Intellective Experiments

The first step in developing a new computational organizational model is to specify the behaviors of study and thus the micro-theories to be incorporated. We must use *toy problems* to assess whether we have encoded micro-behaviors correctly within the simulation engine, and whether these micro-behaviors generate predictable macro-behaviors. This initial validation step is critical—once micro-behaviors are encoded within a computational framework, they are taken as axiomatic. In validating the systems micro-behavior, researchers must observe whether the model behaves as predicted by the theories and observations of micro-behavior.

To validate the interactions of axioms and the emergent macro-behavior of our simulation, we used *intellective simulations*. Intellective simulations are idealized simulations that use extremes of input-parameter values to examine hypothetical problems in idealized settings. In these simulations, a researcher would vary one or two variables through a range of values to assess the computational limits of their framework, and the way in which the axioms encoded in the simulation interact. Although there may be no real-world counterpart to these simulations, these isolated toy problems answer the question: “Do the micro-theories produce qualitatively correct macro outcomes?” The results of these simulations are compared to the outcomes predicted by organization theory. Concordance of intellective simulation predictions and those predicted by organizational theory lends support that the micro-theories and their interactions have been correctly modeled.

Early in the development of the VTA model, we applied our developing model of how team members interact under varying levels of goal incongruency to a number of small synthetic test cases—“toy” organizations—simple enough models that they could be manually compared to known theory of how agents with different levels of goal incongruency behave. For example, we modeled the process by which managers determine how much decision-making power to grant to subordinates as *selective authority delegation*. High goal incongruency levels will lead managers to demand that a greater proportion of exceptions be reported to them for decision making, while low goal incongruency levels will encourage managers to allow subordinates to handle exceptions on their own. Low levels of authority delegation will, in turn, effectively increase the level of centralization in regard to local decision-making within the organization and provide managers with greater control over the workflow.

As a rule, the perception of high levels of goal incongruency, as well as a propensity for micro-involvement on the part of the manager, will cause a manager to delegate less authority to subordinates (Burton and Obel, 1995) (Figure 4).

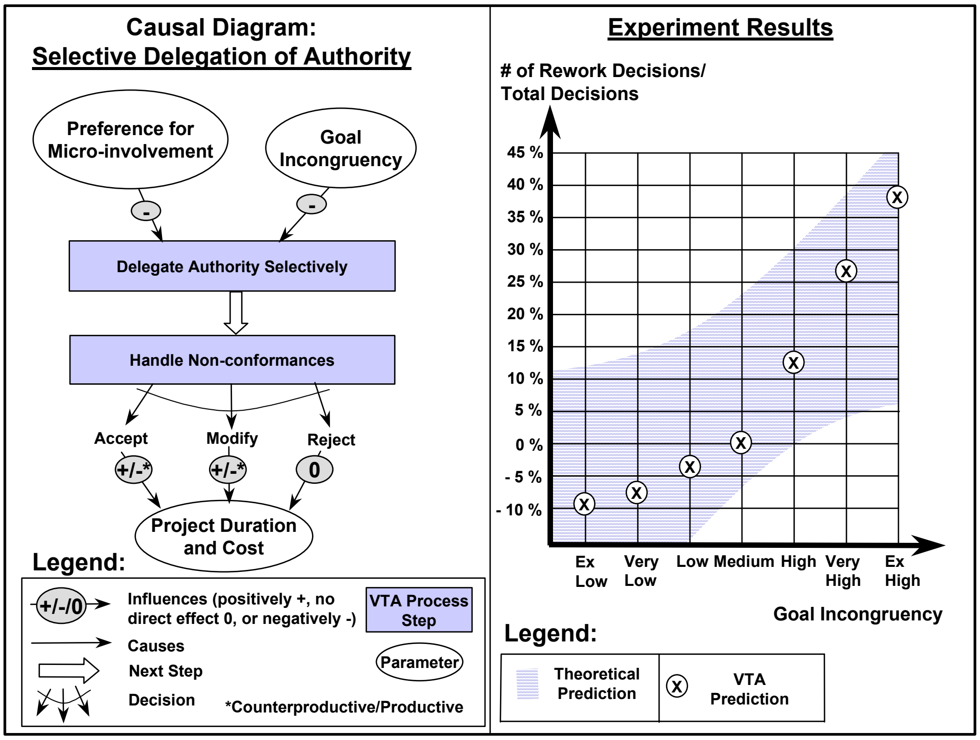

Figure 4: Selective Delegation of Authority. Preference for micro-involvement and goal incongruency determine the distribution of authority in each vertical chain of command. The right part of the figure shows the results from our simulation analysis. Only the exception generation and selective delegation of authority micro-behavioral processes were activated. Simulation results agree qualitatively with organizational contingency theory and they are stable.

Figure 4 shows the results of our intellective experiments. The shaded area shows the qualitative predictions of theory, with the VTA results shown as circles. Over the range of goal incongruency in our model, we found our results fell within the range predicted by theory, and as goal incongruency increased, the cost and duration of the project increased. This suggests that we had encoded the "axiomatic" micro-behaviors of agents in response to goal incongruency correctly (Thomsen *et al*, 1998b).

3.2 Validation of Reasoning and Representation

The second component of our validation trajectory—validation of reasoning and representation—assesses the ability of a researcher to model and simulate a real organization using the emulation system. To reproduce the behaviors of an organization, the representation of the simulation model must be able to capture relevant features of the organization and work process, and the axioms of micro-behavior must be able to reason about those features to generate realistic macro-behaviors. The reasoning of the simulation may be correct, but if we are unable to accurately capture real-world data, we are limited to examining only theoretic and intellective questions. Validation of reasoning and representation is thus a necessary step to bridge between the theory made operational in a simulation, and the application of that theory to real-world situations. In our validation trajectory, we describe three sub-components that comprise the validation of reasoning and representation: validation of authenticity, validation of generalizability and validation of reproducibility, and apply it to validation of goal incongruency within VTA.

3.2.1 Validation of Authenticity

Validation of authenticity answers two questions: "Can we represent a real organization with our simulation model?" and "Can we emulate quantitatively relevant performance characteristics of the organization?" Validation of authenticity involves gathering information from the real-world and translating that information into a symbolic language that a computer simulation can understand. In developing VTA, we needed a modeling language and framework that could capture, represent, and quantify agency and contingency theory constructs such as goal incongruency in an authentic, generalizable, and reproducible manner.

We developed a methodology for gathering data on goal incongruency within the Norne project team based on Chatman's (1991) card-sort method. We asked the project manager to list the most important project goals. Each project participant was asked to sort a card-set of these project goals in order of his or her priority. We calculated the distance in goal priorities between project participants by simply summing up the absolute differences in the ranking of each goal. Table 1 shows the result of the Piping Leader and Project Manager's ranking.

Goal	Rank Piping Leader	Rank Project Manager	Rank |difference|
Duration	2	1	|2 - 1| = 1
Cost	5	5	|5 - 5| = 0
Quality	3	4	|3 - 4| = 1
Safety	1	2	|1 - 2| = 1
Self Improvement	6	6	|6 - 6| = 0
Minimizing Risk	4	3	|4 - 3| = 1
			Sum: 4

Table 1: Goal Incongruency between the Piping Leader and the Project Manager. The resulting goal incongruency between the Project Manager and the Piping Leader is four.

This proved a useful method of capturing and quantifying the abstract notion of goal incongruency between individuals in a project and one that successfully followed the predictions of theory. For example, when specifically asked, the lower-level actors focused on the dimensions of quality most pertinent to their discipline, as the literature on professions predicts (Chiles and McMakin, 1996; Ghosal and Moran, 1996; Nass, 1986). Despite the difficulty that participants had in recalling data from past projects, our technique was capable of capturing enough data to effectively model and simulate goal incongruency in the Norne project.

3.2.2 Validation of Generalizability

Although the ability to model and simulate a particular organization is an important milestone in the trajectory of validation, it does not reassure users of a particular simulation system that the theories, micro-behaviors, and emergent macro-behaviors are generalizable to other organizations. Thus, we must assess whether the model is overfitted to a particular organizational setting.

In the course of development, we applied VTA to four different project teams over three-year period (Thomsen, 1998)— the Lockheed Launch Vehicle Avionics and Structures Project (Thomsen and Kwon, 1996)., the Norne Subsea Satellite Design Project (Thomsen *et al*, 1998a) and the A2100 Pyrovalve Development Project (Thomsen *et al*, 1998c). In each case, we found the card-sorting technique useful to quantify the abstract qualities of goal incongruency, and found that differences in goal incongruency resulted in predictable differences in organizational performance consistent with organizational theory's predictions. Organizational theory qualitatively predicts that goal incongruency can increase the diversity of behavioral repertoires available to the project to meet the requirements imposed by the environment and therefore improve the project performance, e.g., reduce project cost (Weick, 1979). At the same time, organization theory indicates that too much goal incongruency can lead to time consuming arguments and undermine project performance, e.g., increase project cost (March and Simon, 1993). Hence, organization theory predicts a curvilinear relationship between goal incongruency and project cost (figure 5).

Project managers who understand their work processes well could relate requirements to the process and assign activities to different, specialized individuals. It was surprisingly easy and fast (about three meetings that lasted for about one hour) for our cooperating project manager on the Pyrovalve Development Project to describe the activities, actors and their attributes (indicating the relevance of our conceptualization to practical project management).

3.2.3 Validation of Reproducibility

Finally validation of reproducibility (inter-rater reliability) validates whether two modelers will get the same results when they model and simulate the same organization. In all modeling enterprises, it is imperative that precautions are taken to ensure that any given model remains undistorted by inter-rater biases or variations in procedure on the part of the modeler. Input data are subject to strong biases that reflect the personal background of the modeler.

Whenever possible, we attempted to derive input data using a formalized methodology, e.g., activity complexity, activity interdependence strength, and goal incongruency in VTA (Thomsen et al., 1998a). The methodology nevertheless requires some skill and judgement. On two of our case-projects, Lockheed Launch Vehicle Project and A2100 Pyrovalve Development Project, two different modelers modeled the same project. Although the models were not identical, the results of the simulations were similar, and the conclusions of those models were the same. Presently, we have limited results of inter-rater validity checks using different models and modelers. However, as our experience with VTA expands and more researchers use the system, we anticipate building our case for the inter-rater validity.

3.3 Validation of Reasoning, Representation and Usefulness

In the validation of the VTA system, the previous experiments to validate the reasoning and representation are a necessary precursor to the more complex and important validation of reasoning, representation, and usefulness. Once we are assured that these lower-level validation experiments produce valid results, we can examine how a simulation systems functions in replicating, predicting, and changing the performance of a real-world organization.

This portion of our validation trajectory is composed of four sub-experiments: retrospective, gedanken, natural history, and prospective experiments with interventions. Retrospective experiments attempt to duplicate past performance using retrospective data. Although retrospective experiments have inherent biases from using retrospective data, they are a necessary step to calibrate the model for future experiments. *Gedanken* experiments build on retrospective evaluations, and answer "what-if" thought experiments. The predicted outcomes of these thought experiments are compared to the predictions of theory and to the predictions of organizational experts. Natural history experiments identify organization problems and then follow the organization through time to see those problems develop. Finally, prospective interventions identify problems and predict organizational performance if those solutions are applied. Natural history experiments predict the future—prospective intervention experiments not only predict future performance, but also attempt to predict how suggested interventions might change the future.

Our validation of VTA concentrated on these aspects of the validation trajectory. Earlier validation of our model with toy problems, intellective simulations, and evaluation of representation culminated in an extensive, real-world evaluation of the VTA system.

3.3.1 Retrospective Validation

A retrospective experiment duplicates past performance, using a simulation model, and calibrates the model as needed to reproduce previous experiences. As with all retrospective studies, there is a bias in the way in which data is modeled based on the known outcomes, but it is a necessary first step to simulate real world phenomenon.

In the Norne Subsea Satellite Design project, VTA used data from completed projects to calibrate the internal variables of the project. After adjusting VTA calibration parameters to reflect past project outcome data, we were able to reproduce successfully the project outcomes on the Norne Subsea Satellite Design Project. This is shown in figure 5.

3.3.2 *Gedanken* Validation of Hypotheses

Gedanken validations are named for the German verb *gedanken*, which means *to think*. These validations ask "*what-if*" questions of experts, the simulation system, and theory, and then compare the answers. *Gedanken* experiments are similar to intellective simulation, but use real, rather than idealized, organizations.

A gedanken experiment takes retrospective validation one step further and postulates a hypothetical, "what-if" scenario. The simulation of this hypothetical scenario is then compared to (1) theory (to make sure it is consistent with theory) and (2) to predictions made by managers in the organizations. For example, if you asked the managers "what would happen if we let the team leaders and team members make the quality decisions, rather than the project manager?" they could predict the effect on the organization, the quality, the time, cost, etc. The researcher would run the simulation, and compare the results to both theory and expert predictions.

After retrospectively validating VTA, we asked the project manager to make predictions about the effect of hypothetical changes to key input variables in the project's initial configuration (e.g., goal incongruency between actors) on dependent measures of time, cost, and process quality. We compared our simulated model predictions with the project's actual outcome as well as with those of the manager's "what-if" scenarios. We ran t-tests on the data to show that the manager's prediction and the simulation results were statistically consistent. An example is given in figure 5 below.

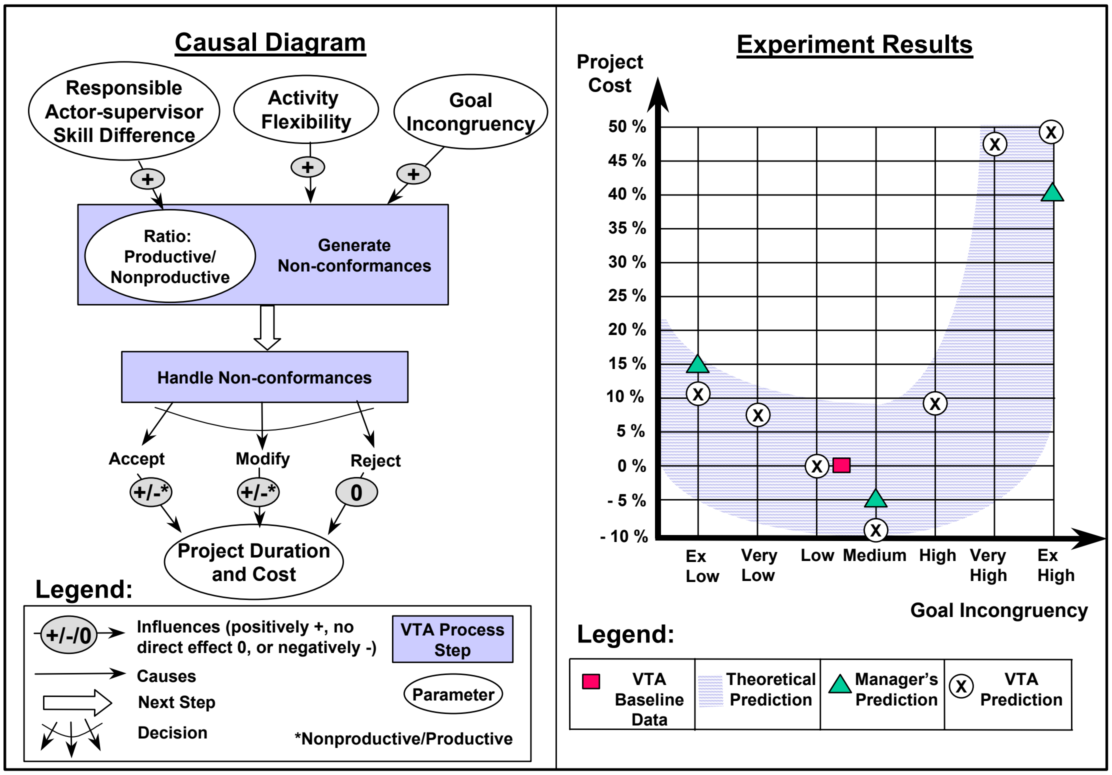

Figure 5: The Effect of Responsible Actor-supervisor Skill Difference, Activity Flexibility, and Goal Incongruency on the Generation of Non-conformances (NC). Activity flexibility and goal incongruency between the supervisor and subordinate determine whether a NC is generated. Once generated, the responsible actor-supervisor skill difference determines the effect that the NC exception is likely to have on project duration and cost. The right part of the figure shows the results from our simulation analysis. Our simulation experiments predicted that the project cost could have been better (by about 5-10%) if the project participants had had slightly more goal incongruency.

Since VTA make operational qualitative organizational theory, the aggregate predictions of the model about the effect on a dependent variable (e.g., cost) caused by a change in a relevant input variable (e.g., goal incongruency) can be tested qualitatively against the predictions of the textual theory as well. VTA simulation results agreed qualitatively with this macro-organizational theory. This validation method has the advantage of validating a simulation system on test cases of realistic scale, but it provides no evidence that the modeling method can be used in practice to support organizational design decisions. The ability to capture salient features of a realistic project and calibrate the values of model attributes demonstrates representational validity. Retrospective validation also provides insights into the cause-and-effect relationship between different calibration parameters and project performance (Thomsen *et al.*, 1998a).

3.3.3 Natural History Validation

Gedanken validation experiments have the advantage of being able to rapidly test a simulation model and see how well it performs when compared to known theory and to expert opinions. However, a more robust validation test is a natural history experiment. In this validation experiment, an organization is modeled, the future results of the project predicted, and the organization observed to see if performance predictions come true.

In our natural history experiments, we applied our model to two on-going, real-world test cases (Avionics and Structures team on the Lockheed Launch Vehicle project) and performed a series of experiments that produced forward predictions about the remaining project outcomes. This method is more robust in that the researcher cannot "curve fit" calibration parameters to unknown future performance benchmarks.

For the Lockheed Launch Vehicle Avionics project team test cases, VTA correctly predicted the risk of backlog in the external team developing an outsourced component of the avionics package, as well as a serious quality problem and resulting delays. In the other contemporaneous Lockheed Launch Vehicle Structures project team test case, no problems were predicted and none occurred.

Because of a lack of sufficient prior experience with the modeling methodology, neither the investigators nor the project management intervened in the Avionics product development process based on our model predictions. The backlog and its impacts later materialized exactly when and where predicted, and had to be managed with a subsequent high impact on project cost and schedule. Moreover, during the demonstration launch, the launch vehicle veered off-course, and range control operators detonated the vehicle, along with its commercial payload. The subsequent analysis revealed two anomalies that caused loss of the demonstration launch vehicle:

- The first anomaly occurred 80 seconds after liftoff, when the vehicle suddenly pitched nose up. The pitch-up occurred because an electrical cable between the first-stage controller and the pitch actuator in the thrust vector control system experienced heating during flight in excess of its specifications.
- The second anomaly occurred 127 seconds after liftoff. The vehicle's inertial measurement unit (IMU), supplied by a subcontracting company, malfunctioned due to electrical arcing within the unit. The arcing was caused by exposing the high

voltage circuits within the IMU to the low atmospheric pressure at high altitudes (LMMS Press Release, 1995).

The launch vehicle's instrumentation system provided extensive analog and digital data, enabling detailed analysis of the two anomalies. A company-led Failure Review Board was established to identify the cause of the loss of the vehicle and to recommend changes to eliminate the problems. The recommended changes to cables and flight-boxes were implemented, and the launch vehicle returned to flight successfully in 1997 (LMMS Press Release, 1997).

The VTA analysis predicted severe backlog problems in both the Cables and Flight-boxes subteams. The disastrous result of the first launch was caused by problems in the areas of responsibility of the Cables and Flight-boxes subteams. Our model results, therefore, provide ample evidence that product quality relates to process quality. The intuitive notion that the quality of an organization work processes affect ultimate product quality has also been demonstrated convincingly by several researchers in the facility engineering domain, most recently by Fergusson (1993). Hence models like VTA, which generate predictions of process quality, can provide indications of the levels of risk for product quality problems in particular subsystems.

Thus, the study provided evidence not only about the representational validity of our model but also about its predictive power. From a managerial perspective, however, the value of contemporaneous modeling is limited, because it is more difficult to initiate interventions and mitigate risks in an ongoing project than to do this at the outset of a project (Thomsen, 1998).

3.3.4 Prospective Validation with Interventions

Finally, the best test of the usefulness of a simulation model is when it is used by managers to commit real organizational resources in order to improve future organization performance. In prospective validation with interventions, we not only predict the future, but also attempt to change the future based on the results of the simulation. Managers must have faith in the validity of the model if they are willing to commit real resources based on the simulation results.

In VTA, after the success in predicting the performance of the Lockheed launch vehicle, managers within the organization were convinced to cooperate with a prospective validation that incorporated the recommendations of the simulation model. In the last of our case studies, we modeled the planned work process and organization on the A2100 Pyrovalve Development project and prospectively identified potential project performance problems. After considering our recommendations, the cooperating manager intervened in the engineering process to reduce some of the organizational risks that the model had predicted might adversely affect project performance. In our subsequent observations of the project, the potential risks that our model initially identified as being likely to affect project performance adversely were avoided by this intervention. This prospective validation method has the advantage of providing representational validity and predictive power. Moreover, it demonstrates that our model could have significant value from a managerial perspective. We can thus claim that we have evidence of VTA's usefulness for practitioners (Thomsen *et al*., 1998c).

4. Discussion and Conclusion

Since one our long-range research goal is to provide project managers with a theory and tools to predict project behavior and performance through the development and analysis of a computational organizational model, it is extremely important that the model capture the key aspects of a project that determine project performance. The success of predicting emergent project behavior is fundamentally contingent on the accuracy and relevance of the rules of behavior that have been posited for the system at the micro-level. The assumptions regarding the nature of the constituent elements, as well as the rules that govern their interaction, determine the extent to which the emergent behavior generated by the simulation model will agree with both theory and real-world behavior. In order to ensure that our model captures the essentials of project behavior, extensive real-world validation is necessary.

We have described a methodology we believe is useful to validate emulation simulation models, and show how each experiments contributes to the overall validity of the simulation and its results. However, we believe that this methodology is also useful for other researchers in computational organization theory.

For example, researchers interested only in theory would conduct intellective experiments, based on stylized models, and test the sensitivity of the model to changes in input parameters. The results then can be compared to existing theory, or if new behaviors are observed, new macro-level theory discovered using simulation. Investigations of group decision-making, organizational learning, and others can be validated using experiments that assess reasoning.

Likewise, investigators interested in macro-behaviors can use experiments in reasoning and representation to evaluate whether their theories have captured the essential elements of the organization and can reason about these representations using computer simulation.

Ultimately, the goal of computational organization theory is to better understand organizations using computer tools to develop new theory and better understand organization behavior. To be confident in their results, researchers in computational organization theory must develop systematic ways of evaluating and validating their computational models. In this paper, we outline a trajectory of experiments which "builds a case" for the validity of a computation model and describe how we applied this technique to a computational model of goal incongruency and the effect of different levels of incongruency have on organizational behavior.

With complex computational models, although it is always desirable to have statistical results, it is difficult to produce results with statistical significance. Statistical evidence of predictive validity and efficacy of our model will come only from a series of intervention studies done concurrently with similar studies done without intervention. However, there are benefits to computational simulations that cannot be captured with statistical significance testing. Researchers may gain new insight into organizational behavior, new theories can be developed, and as case for validation is built on experience and a consistent validation strategy, project managers will gain confident in the results. It may not be possible to show the statistical significance of finite element analysis systems and the way they assist in construction design, but is not necessary to do so—designers understand and trust the results of finite element analysis tools. As emulation model gain credibility, we believe computer simulations of organizations will be seen as an important tool in organization design and project management. Our trajectory of validation for computational models is general enough to be useful for both statistical and non-statistical evaluation strategies.

Additional experiments are always possible, and as new evaluation techniques are developed, they can contribute to the "case for validity" in computational models. For example, we have proposed to do cross-model validation, i.e., "docking" of different models (Axtell *et al*., 1996), between VTA and OrgCon (Burton and Obel, 1995). OrgCon is a heuristic implementation of macro-contingency theory, and VTA links micro-behaviors of organizational participant to the macro-level contingency theory predictions. Since, both OrgCon and VTA are based on organizational contingency theory and an information-processing perspective of work, they use a consistent theoretical platform. It would, therefore, be both theoretically sound and interesting to judge the degree to which the two models correspond in their recommended interventions for a particular organization. This form of cross-model validation would build on our trajectory of validation and support both evaluations of reasoning and representation.

5. Acknowledgments

We would like to express our appreciation to the project teams in our collaborating aerospace and oil companies for their generous time and efforts in helping us to develop the computational models that we used as our case studies. We would also like to thank Yul J. Kwon for invaluable help during the data collection phase of our research.

6. References Cited

Axtell, R., R. Axelrod, J. J. Epstein and M. D. Cohen (1996), "Aligning Simulation Models: A Case Study and Results," *Computational and Mathematical Organization Theory*, 1(2), 123-142.

Baligh, H. H., R. M Burton and B. Obel (1994), "Validating the Organizational Consultant on the Fly," in *Computational Organization Theory*, edited by K. M. Carley and M. J. Prietula, Hillsdale, NJ: Erlbaum Associates.

Burton, R. M. and B. Obel (1995), *Strategic Organization Diagnosis and Design: Developing Theory for Application*. Boston: Kluwer Academic Publishers.

Carley, K. M. (1995), "Computational and Mathematical Organization Theory: Perspectives and Directions," *Computational and Mathematical Organizational Theory*, 1(1), 39-56.

Carley, K. M. and D. M. Svoboda (1996), "Modeling Organizational Adaptation as Simulated Annealing Process*," Sociological Methods & Research*, 25(1), 138-168.

Carley, K. M. (1997), *Validating Computational Models*. Working Paper: Social and Decision Sciences, Carnegie Mellon University, Pittsburgh, PA.

Carley, K. M. and Z. Lin (1995), "Organizational "Designs Suited to High Performance Under Stress," *IEEE Transactions on Systems, Man, and Cybernetics, 25(1), 221-231.*

Carley, K. M. and Z. Lin (1997), "A Theoretical Study of Organizational Performance Under Information Distortion," *Management Science*, 43(7), 977-997.

Chiles, T. H. and J. F. McMackin (1996), "Integrating variable risk preferences, trust, and transaction cost economics," *Academy of Management Review*, 21(1), 73-99.

Chatman, J. A. (1991), "Matching people and organizations: Selection and socialization in public accounting firms," *Administrative Science Quarterly* 36(3), 459-484.

Christiansen, T. R. (1993), *Modeling the Efficiency and Effectiveness of Coordination in Engineering Design Teams*. Ph.D. Dissertation, Department of Civil Engineering, Stanford University. Published as Det Norske Veritas Research Report No. 93-2063, Oslo, Norway.

Christensen, L.C., T. R. Christiansen, Y. Jin, J. C. Kunz and R. E. Levitt (1999), "Modeling and Simlating Coordination in Projects," *Journal of Organizational Computating and Electronic Commerce*, 9(1), 33-56.

Cohen, G. P. (1992), *The Virtual Design Team: An Object-Oriented Model of Information Sharing in Project Teams*. Ph.D. Dissertation, Department of Civil Engineering, Stanford University.

Cyert, R. M. and J. G. March (1992), *A Behavioral Theory of the Firm* (2nd edition). Cambridge, MA:Blackwell Publisers (1st edition 1963).

Fergusson, K. J. (1993), *Impact of Integration on Industrial Facility Quality*. Ph.D. Dissertation, Department of Civil Engineering, Stanford University.

Friedman, C. P and J. G. Wyatt (1997), *Evaluation Methods in Medical Informatics*, New York: Springer-Verlag.

Fridsma, D. B. (1998), "Organizational Simulation of Medical Work: An Information-Processing Approach ", PhD Proposal, Stanford Medical Informatics, Stanford CA, 1998.

Galbraith, J. R. (1973), *Designing Complex Organizations*. Reading, MA: Addison-Wesley.

Galbraith, J. R. (1977), *Organization Design*. Reading, MA: Addison-Wesley.

Ghoshal, S. and P. Moran, P. (1996), "Bad for practice: A critique of the transaction cost theory." *Academy of Management Review*, 21(1), 13-47.

Huberman, B. A. and T. Hogg (1995), “Communities of Practice: Performance and Evolution,” *Computational and Mathematical Theory*, 1(1), 73-92.

Hyatt, A., N. Contractor, and P. M. Jones (1997), “Computational organizational network modeling: Strategies and an example*,” Computational and Mathematical Organizational Theory*, 2(4), 285-300.

Jin, Y. and R. E. Levitt (1996), "The Virtual Design Team: A Computational model of Project Organizations*," Computational and Mathematical Organizational Theory*, 2(3), 171-196.

Kleindorfer, G. B., L O’Neill and R. Ganeshan (1998), “Validation in Simulation: Various Positions in the Philosophy of Science,” *Management Science*, 44(8), 1087-1099

Law, A. M. and D. Kelton (1991), *Simulation Modeling and Analysis* (2nd edition). New York, NY: McGraw-Hill.

LMMS (Lockheed Martin Missile and Space) Press Release, December 1995. “LMLV-1 Loss Linked To Two In-flight Anomalies.”

LMMS (Lockheed Martin Missile and Space) Press Release, August 1997. “Lockheed Martin Launch Vehicle Successfully Launches NASA/TRW Lewis Satellite.”

March, J. G and H. A. Simon (1993), *Organizations* (2nd edition). Cambridge: Blackwell Publishers (1st edition 1958).

Masuch, M. and P. LaPotin (1989), “Beyond Garbage Cans: An AI Model of Organizational Choice,” *Administrative Science Quarterly*, 34(1), 38-67.

Moder, J. J., C. R. Phillips and E. W. Davis (1983), *Project Management with CPM, PERT, and Precedence Diagramming* (3rd edition). New York: Van Nostrand Reinhold (1st edition 1964).

Nass, C. I. (1986), "Bureaucracy, Technical Expertise, and Professionals: A Weberian Approach," *Sociological Theory*, 4, 61-70.

Oreskes, N., K. Shrader-Frechette and K. Belitz (1994), “Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences,” *Science*, 263:641-636.

Simon, H. A (1996), *The Sciences of the Artificial* (3rd edition). Cambridge, MA: MIT Press.

Simon, H. A. (1997), *Administrative Behavior* (4th edition). New York: Macmillan (1st edition 1945).

Simon, H. A. (1998), “Simulation,” in *Handbook of Economic Methodology* (eds. J. B. Davis, D. W. Hands and U. Maki), 458-462.

Thompson, J. D. (1967), *Organizations in Action: Social Science Bases in Administrative Theory.* New York: McGraw-Hill.

Thomsen, J. (1998), *The Virtual Team Alliance (VTA): Modeling the Effects of Goal Incongruency in Semi-routine, Fast-paced Project Organizations*. Ph.D. Dissertation, Department of Civil Engineering, Stanford University. Published as Det Norske Veritas Research Report No. 98-2024, Oslo, Norway.

Thomsen, J. and Y. J. Kwon (1996), *Modeling the Lockheed Launch Vehicle Program*. DNV Research Report No. 96-2025, Oslo, Norway.

Thomsen, J., Y. J. Kwon, J. C. Kunz and R. E. Levitt (1996), "A Computational Approach to Modeling an Engineering Design Team," in *Proceedings of the Third Congress on Computing in Civil Engineering*, ASCE, Anaheim, CA, June 17-19.

Thomsen, J., M. A. Fischer and R. E. Levitt (1998a), *The Virtual Team Alliance (VTA):* An *Extended Theory of Coordination in Concurrent Product Development Projects*. CIFE Working Paper #44, Stanford University.

Thomsen, J., R. E. Levitt and C. I. Nass (1998b), *The Virtual Team Alliance (VTA): Extending Galbraith's Information-processing Model to Account for Goal Incongruency*. CIFE Working Paper #45, Stanford University.

Thomsen, J., J. C. Kunz and R. E. Levitt (1998c), *Designing Quality into Project Organizations through Computational Organizational Simulation*. CIFE Working Paper #46, Stanford University.

Tushman, M., and D. Nadler (1978), "Information Processing as an Integrating Concept in Organizational Design," *Academy of Management Review*, 3, 613-624.

Weick, K. E. (1979), *The Social Psychology of Organizing*. McGraw-Hill Inc.