An Agent-based Simulation Study for Exploring Organizational Adaptation
Jiang Wu, Bin Hu, Yu Zhang, Catherine Spence, Steven B. Hall and Kathleen M. Carley
SIMULATION 2009 85: 397
DOI: 10.1177/0037549709105267
The online version of this article can be found at:
http://sim.sagepub.com/content/85/6/397
An Agent-based Simulation Study for Exploring Organizational Adaptation

Jiang Wu
Bin Hu
Huazhong University of Science and Technology, China
bin_hu@mail.hust.edu.cn

Yu Zhang
Trinity University, San Antonio, TX, USA

Catherine Spence
Intel Corporation, USA

Steven B. Hall
Lockheed Martin, USA

Kathleen M. Carley
Carnegie Mellon University, Pittsburgh, PA, USA

Agile enterprises with different organizational structures manifest different organizational behaviors when responding to environmental changes. In this paper, we use a computational model to examine organizational adaptation on four dimensions: Agility, Robustness, Resilience, and Survivability. We analyze the dynamics of organizational adaptation by a simulation study on the interaction between tasks and organization in a sales enterprise. The ‘what if’ analyses in different scenarios show that more flexible communication between employees and less hierarchy level with the suitable centralization can improve organizational adaptation. The developed simulation model supports the exploration of the parametric space that defines alternative organizing processes for the optimal strategy given the specified environmental dynamics.

Keywords: organizational adaptation, agility, robustness, resilience, survivability, simulation

1. Introduction

In the information era, rapid technological changes, extensive globalization, and intense competition have created significant pressures on organizations. The agile organization [1] is an appropriate alternative to the bureaucratic model under these conditions. When building an agile organization, one of the most essential issues is how to build an organization that can respond rapidly to the changing business environment. Organizational researchers have long recognized the value of formal models – mathematical, logical, computational – for examining organizational behavior in general and organizational adaptation in particular [2–7]. However, it is still challenging to identify the organizational adaptation and examine the optimal organizational structure that adapts to the environment change.

Research into organizational adaptation is a complex issue because the relationships are intricate, multiple participants are involved in multiple interactions over time and interactions are nonlinear. Nonlinear phenomena, with their feedback loops, are difficult to study with the classical inductive case methods or with standard statis-
tical techniques. Furthermore, these phenomena are be-
coming of increasing academic interest as theoretical de-
velopments move from cross-sectional and equilibrium
perspectives to dynamic ones [8]. Additionally, networks
composed of multiple agents are inherently computational
since they have a need to scan and observe their envi-
ronment, store facts and programs, communicate among
members and with their environment, and transform in-
formation by human or automated decision making [9].
Consequently computer-based simulation can be used for
theory development and hypothesis generation [10]. Sim-
ple, but non-linear processes often underlie the team and
group behavior. Computational analysis enables the the-
orist to think through the possible ramifications of such
non-linear processes and to develop a series of consist-
ent predictions. Simulations are also particularly valuable
when we seek to explain longitudinal phenomena that are
challenging to study using empirical methods because of
their time and data demands [4].

Particularly, agent-based simulations can give insights
into the ‘emergence’ of macro-level phenomena from
micro-level actions [11], and enable examination of how
sensitively the simple local rules affect the final results
using sensitivity analysis [12]. OrgAhead [13] was one of
the first computational models used to study organization
adaptation. It focuses on organizational learning designed
to test different forms of organizations under a common
adaptation. Subsequently, Epstein built an organi-
izational adaptation model in which individual agents en-
dogenously generate internal organizational structure to
adapt optimally to dynamic environment [14]. These two
previous models only include one dimension of measur-
ing adaptation performance. They both mention the ac-
complishment ratio of completed tasks to all the tasks as a
measure for organizational adaptation. They observe this
ratio under different organizational structures. While orga-
nizational structure changes are made to adapt to the task
environment change, task accomplishment and schedule
are also affected by the change of organizational structure.
Organizational adaptation has two different levels: strate-
gic and operational [15], and furthermore it should involve
more dimensions besides accomplishment ratio.

In this paper, we propose a new computational model
of organizational adaptation that expands Epstein’s model
so as to be suitable to explore the different dimensions of
adaptation – Agility, Robustness, Resilience and Surviv-
ability – and observe the optimal organizational structure
for these dimensions of adaptation. In this paper, an or-
ganization, termed adaptive, can generate new strategies
and/or reconfigure its structure to potentially achieve even
higher performance [3]. However, a robust organization is
able to sustain high levels of performance in dynamic en-
vironments without having to change its structures. Ro-
bustness involves the ability of the system to survive vari-
atations in structural/internal parameters without disrupting
its behavior. This would relate to loss of human resource
in the company, cost of loss and cost/delay in replacing
the nodes. These four dimensions have different centered
goals:

- **Agility** refers to how fast an organization reacts to
the changing environment (this paper uses ‘average
velocity’ to measure this)

- **Robustness** measures how stable an organization
can follow the expected output when the environ-
ment fluctuates (this paper uses ‘deviation’ to mea-
ure this)

- **Resilience** represents how large of an output amplitu-
de deviation an organization can tolerate and still
finally return to the expected output level (this paper
uses ‘magnitude’ to measure this)

- **Survivability** focuses on how long the systems can
be resilient over time to survive (this paper uses ‘du-
ration time in stable’ to measure this). Resilience is
the superset of survivability.

The computational model in this paper is agent based
and is designed to address the issue of organizational
adaptation. We consider the hierarchy, span of control
and communication culture among employees as the repre-
sentation of organizational structure. The internal en-
vironment changes with the hiring or firing of employ-
ees, and the external environment changes with increas-
ning or decreasing sales opportunities. Actually, in orga-
nizational research, numerous studies focus on the orga-
nizational structure [1, 16, 17]. Most importantly, organi-
nizational structure can affect the organizational change [17,
18]. The organizational structure includes five dimen-
sions [19]:

1. Specialization
2. Standardization
3. Formalization
4. Centralization
5. Configuration.

We examine the centralization and configuration dimen-
sions of organizational structure. These two dimensions
are complex and decided by many factors including hu-
man behavior. In this paper, we use simulation to study
these two dimensions of organizational structure on the
four dimensions of organizational adaptation. We assume
the enterprise in this paper is a sales company whose ma-
jor tasks are to recognize and grasp sales opportunities.
Thus, the central issue is to build a simulation model on
the interaction between organizational structure and task
environment so as to regard it as a test bed to examine
the ‘fast’, ‘stable’, ‘large’ and ‘long’ dimensions of orga-
nizational adaptation. Also, we use the cumulative bank
balance related to revenue, cost and profit as the main measurement to observe the dynamics of organizational adaptation. Our objective is to discover insights about organizational adaptation from the simulation study on interaction between organization and task. Our computational model, Modeling Agility, Robustness, Resilience and Survivability of Organizational Adaptation System (MARRS), is designed especially for examining four dimensions of organizational adaptation. We use the same presentations of organizational structure and environment as Epstein’s model, but our model has five major differences [14]:

1. MARRS has a bank accounting balance to count the organizational adaptation performance; this bank accounting is specially designed for examining four dimensions of organizational adaptation; Epstein’s model does not include this.

2. MARRS utilizes the different one-level communication and up-downward communication mechanism to make it suitable for simulating and examining the different dimensions of organizational adaptation.

3. MARRS adds the parameter setting of ‘Max level’ for examining the impact of dynamic hierarchy level on organizational adaptation; Epstein’s model does not need this.

4. The change of number of workers and sales opportunities is allowed during the simulation, so it is easy to set different scenarios that show the change of internal or external environment

5. MARRS uses a different agent-based platform, NetLogo (http://ccl.northwestern.edu/netlogo/), while Epstein’s model is developed using Ascape (http://ascape.sourceforge.net/); MARRS has been firstly aligned with and then expanded from Epstein’s model.

The paper is structured as follows. Section 2 reviews the literature related to the research of organizational adaptation and introduces the background of agile organization. In Section 3, we propose a new computational model that is used to examine the different dimensions of organizational adaptation. Section 4 specifies the design of our virtual experiments. In Section 5, through a series of virtual experiments (simulations), we observe the organizational agility, robustness, resilience and survivability. In Section 6, we discuss the implications from organizational adaptation research. Section 7 concludes this paper.

2. Background and Literature Review

The Agile Enterprise uses concepts from complexity science, which is based on the assumption that relationships between actors are autonomous and continuous [1]. The Agile Enterprise relies on the ability of its participants to rapidly evaluate feedback and new information, to continuously learn, and to morph and evolve as needed, often spontaneously. For an agile enterprise, competitiveness is a constantly moving target. This type of organization strives to maximize its responsiveness to changes in the competitive environment while minimizing internal trauma resulting from change [20]. This means the organization must be able to continuously evolve, while maintaining a high level of performance, which drives organizational sustainability. Outward agility requires rapid innovation by exploring new opportunities; exploiting the marketplace by delivering new products, services, or solutions; adapting to changing market conditions by incorporating feedback; and exiting markets when appropriate [21]. Brafman and Beckstrom offer eight characteristics of a starfish organization that are consistent with views of the Agile Enterprise, and the most important issue for an agile organization is how to build an organization that is adaptive to the rapid changing of business environment [22].

For an organization to achieve marketplace agility, it must be organized in a way that supports continuous change. External adaptability derives primarily from a self-organizing workforce. For this type of organization to succeed, its employees must be open to new ideas and be able to collaborate with others to accomplish shared goals. Workforce scalability facilitates this process. Workforce scalability consists of two components: workforce alignments (WAs) and workforce fluidity (WF) [23]. WAs exist when Human Resources reconfigure in ways that bring them and their activities in synch with changing marketplace demands. WF reflects the ease, speed, and cost effectiveness with which these constant reconfigurations are achieved. In brief, marketplace agility is achieved through organizational agility which, in turn, is facilitated by workforce scalability.

Organizational adaptation is the result of the interaction between organization and tasks [24]. While organizational structure changes are made to adapt to the task environment change, task accomplishment and schedule are also affected by the change of organizational structure. Organizational adaptation has two different levels: strategic and operational [15]. The adaptation on the operational level, implementing local changes, is similar in concept to workload balancing. Perdu and Levis defined operational adaptation to offloading of tasks to other decision makers when the number of waiting tasks reached a maximum value [25]. The adaptation on the strategic level, implementing global changes, releases the constraint on maintaining a fixed process associated with a task, representing a change in strategy for completing a task [26]. Organizations using local change as an adaptation mechanism have concentrated on changing organizational structure to maintain performance [27] or allowing tasks or resources to be transferred among the decision makers [25]. These
organizations have the ability to adapt to task demands in order to maintain the perceived stress at tolerable levels while maintaining team performance. In this paper, our model presents the organizational adaptation on the operational level. The span of control, hierarchy and communication between people are changed locally, and we do not guarantee the reengineering process can provide organizational adaptation on the strategic level.

It is necessary to regard an organization as a complex adaptive system and use complexity theory as a computational/analytical approach [28]. Computational models have been used extensively in this regard, so much so that a new discipline, Computational Organization Theory, has developed to discuss and explore such models [4]. If the traditional empirical research is directed toward longitudinal observation, the accurate and continuous collection of data in a period of time is more difficult. Also, in the empirical research about the organization, in order to generalize models and theories, researchers need to vary variables such as group size, interaction radius and group structure across a broad range of values. Empirically studying these phenomena under each condition using the survey approaches would be extremely costly. Although the simulation method has some arguments internally, numerous traditional organizational theorists turn to simulation for its powerful data analysis capabilities. Simulations are used to build new theories such as: the research on the dynamics of population in the organization [29]; the research on the dynamic capabilities between firms [30]; and study of the mechanism of organizational learning to manage the discontinuous change [31].

With computational models, Carley found that organizations often alter their structure in response to their performance, however, altering the organizational structure in response to minor shifts tends to limit organizational performance [32]. Carley and Lee also found that change is more important than the amount of change, if organizations are to be adaptive [33]. In this research, performance was used as an indicator of the effectiveness of the change or adaptation. If performance degraded after the change, the change was not considered an adaptation. Additionally, focusing on military C2 (Command and Control) structural adaptation, Carley and Lee developed a computational model tool that is suitable for analyzing the impact of different types of organizational learning on the organizational adaptation [13]. Carley and Svoboda also applied a simulated annealing algorithm [5] to find the optimal organizational adaptive structure, which is represented by span of control and size.

Another issue related to organizational adaptation is coordination research. Coordination is managing dependencies between activities [34]. In the coordination process, it is important to characterize different kinds of dependencies and identify the coordination procedures in order to manage them [34]. Malone has proposed a simple set of coordination structures with certain kinds of information processing involved in organizations and markets [34]. He has connected the mechanisms at micro-level to phenomena at macro-level. Also, in the field of artificial social intelligence, related to coordination, social action, structure and mind have been introduced to understand the mechanism of coordination [35]. Castelfranchi defined different kinds of coordination (reactive versus anticipatory; unilateral versus bilateral; selfish versus collaborative) [35].

3. The Computational Model

Modeling Agility, Robustness, Resilience and Survivability of Organizational Adaptation System (MARRS) is fundamentally expanded from Epstein’s organizational adaptation model [14]. MARRS is an agent-based simulation model and developed using Netlogo. It provides a design/analysis toolkit in which the policies (or traditions) governing the generation of structure and allocation of resources within a self-adaptive self-organizing multi-agent system of systems can be explored, modeled and/or designed. The model provides to the designer/analyst the ability to model how well a particular organization’s management policy will fare in one or more alternative environmental dynamics contexts, and alternatively to design the optimal policies for a given environmental dynamic. The user interface of Netlogo implementation for this model is shown in Figure 1.

The parameters of this model include four categories (refer to details in Appendix A): opportunity generation, worker and manager, coordination, and accounting. The category of coordination parameters is very important because these define the organizational structure. Demand inertia is the willingness to ask for help from trading partners and ranges from 0 (never willing) to 1 (always willing). Supply inertia is the willingness to provide help to your trading partners and ranges from 0 (never willing) to 1 (always willing). Max-hierarchy determines how many levels the hierarchy can expand and also dictates ‘span of control’ on the different levels.

3.1. Agent-based Model

As shown in Figure 1, in the output panel, the red dots represent sales opportunities that move from left to right and can be controlled by the ‘Opportunity’ parameter set. When the organization faces sales opportunities, the managers assign workers to recognize and grasp sales opportunities that are represented by white dots. The opportunities that cannot be intercepted are represented by yellow dots. Enterprise organization is represented by squares in Figure 1, and it is a structure of hierarchy. The workers are located in the zero level in the hierarchy and are in charge of recognizing sales opportunities; the managers are located in the 1–5 levels, and assign tasks to workers and manage task schedules; the managers on the higher level will lead the managers on the lower level. The blue links between
AN AGENT-BASED SIMULATION STUDY FOR EXPLORING ORGANIZATIONAL ADAPTATION

Figure 1. MARRS – Organizational Adaptation Simulation System

employees in Figure 1 represent the span of control for each manager, and the managers on the higher level have larger span of control. The managers on the first level have span of control $2^{1} = 2$, the managers on the second level have span of control $2^{2} = 4$ and so on. When the organization responds to the change of environment, managers can communicate with managers on the same level, and exchange workers to schedule tasks; or turn to the managers on the higher level who will be in charge of the task assignment. Like other agile enterprises, this organization’s structure adapts based on hierarchy level, span of control and communication mechanisms.

To respond to sales opportunities, workers cannot move to other locations by themselves and must be led by the direct managers on the higher level. Managers can decide to assign the workers under their control and move them to certain positions according to the management thresholds from $T_{\text{min}}$ to $T_{\text{max}}$. The following four mechanisms (agents’ rules) are employed to adapt to the changes of the business environment:

1. **Task Scheduling Mechanism**: managers can manage the workers in their own span of control. They can place the workers who are free at time $t$ into the ‘Free List’ and the workers who will meet sales opportunities at time $t + 1$ into the ‘Anticipation List’. Managers will randomly assign the workers in the ‘Free List’ into the ‘Anticipation List’ to adapt to the change of environment at time $t + 1$.

2. **One-level Communication Mechanism**: in the range of their memory length, managers can calculate the lost sales opportunities percentage $P_i$ in their span of control according to Equation (1). If $P_i > T_{\text{max}}$, the manager $i$ demands workers to recognize sales opportunities according to Equation (2); if $P_j < T_{\text{min}}$, the manager $j$ supplies workers to managers who demand workers according to Equation (3). The managers who have demands communicate with other managers on the same level to obtain the supplied workers.

$$P_i = \frac{\text{lost opportunities}}{\text{memory length}}.$$ (1)

$$D_i = (P_i - T_{\text{max}}) \times (1 - \text{demand inertia})$$ (2)

$$S_j = (T_{\text{min}} - P_j) \times (1 - \text{supply inertia})$$ (3)

3. **Upward Communication Mechanism**: if manager $i$ has exhausted all the supplies from the managers on the same level, and still holds the status of $P_i > T_{\text{max}}$ after the ‘upward_inertia’ (see Appendix A) time...
period, the manager \(i\) will turn to the direct manager on the higher level. The maximum upward level is controlled by the ‘Max level’ parameter setting. Figure 2 shows organizational adaptation on the different maximum hierarchy levels.

4. Downward Communication Mechanism: if manager \(j\) still holds the status of \(P_j < T_{\text{min}}\) after the ‘downward inertia’ time period, they will authorize the managers on the lower level to take charge of task scheduling between workers in the range of their span of control.

The bank account balance is used to generate the measurements that examine the four dimensions of organizational adaptation. As shown in the output graph of Figure 1, the ‘Salary’ and ‘Accounting’ parameter settings can control budget and cost. The cost includes salary and transaction. The salaries of busy and of free employees are different. Managers who actively manage workers at time \(t\) obtain more money than managers who are free at time \(t\). The busy managers are paid a bonus in addition to the basic salary.

The ‘fitness’ of a particular self-organizing strategy genome1 is determined by the ‘profit’ (profit = revenue – costs) of the organization as a whole. Costs include the cost of maintaining the resources (managers may cost more than workers to maintain) and the market-oriented transaction costs associated with peer-level horizontal resource trades. Costs also (optionally) include the costs of missed opportunities (the ‘k’ factor, please see Appendix A) that reflect the importance/repercussions of not servicing/engaging opportunities/threats that arrive within a worker’s ‘sector’. Finally the designer/analyst can specify/model organizational ‘start-up’ costs by varying the length of time the organization needs to be able to ‘survive’ on initial reserves (investment capital). Revenue is accumulated by successfully allocating resources to opportunities/threats. Each successfully harvested/engaged opportunity/threat yields additional revenue to the organization. MARRS also provides a suite of parameters that allow the designer/analyst and/or scientist to characterize or fit the dynamics of the opportunity/threat environment. These parameters essentially support the characterization of the ‘density’ of opportunities/threats as well as the rate and duration of changes in the opportunity/threat environment.

3.2. Measuring Agility, Robustness, Resilience and Survivability

In the evolutionary process during simulation, we measure four dimensions of organizational adaptation. Agility is measured by velocity, which represents how fast the organization adapts to changes in the environment (including the internal and external environment). As shown in Figure 3a, the y axis represents the bank balance, and the x axis is the tick time during simulation. Velocity is the average speed of organization balance changing for the period \(T\). Figure 3b shows the measurement of Robustness, which represents the organization’s ability to maintain the expected objective in business in spite of some vibrations due to the change of environment. We use standard deviation to measure Robustness. Resilience is the organization’s tolerance to adapt to a large change of environment and keep the expected objective in the evolutionary process. Magnitude, as illustrated in Figure 3c, measures Resilience of organizational adaptation. This magnitude is the maximum number of workers who were fared when organization can still obtain positive profit, or the maximum opportunities were reduced when the organization can still accumulate positive profit. We have assumed

1. The term ‘genome’ is borrowed from the biological research field to represent the organizational structure. This is the value combination of max-hierarchy, demand-inertia and supply-inertia. The definition of genome in this paper is different from that in Epstein’s model.

2. An analogy can be supplied to explain Resilience further using the human body as an example of business organization. Some people can eat a large amount and become fatter and fatter, but they still can revert to the previous thin status again when they stop excessively eating. The degree from final fat status to initial thin status is different for different people. This degree represents the degree of Resilience of the human body.

---

**Figure 2.** Organizational adaptation on the different maximum hierarchy levels

![Figure 2](image-url)
that an organization will be bankrupt if its bank balance is negative. Thus, as shown in Figure 3d, we use duration to measure the Survivability. In practice, some companies have a wonderful visionary approach which enables them to adapt remarkably well, continue to survive and possibly never die [36]. For these four dimensions of organizational adaptation, how do organizations balance the different dimensions in order to adapt to environmental changes?

### 3.3. Optimization Design

Figure 4 is used to describe the business process of an agile enterprise. If we regard the organization as a black box, budget and tasks are the inputs to the organization, and money will flow out in the form of cost, and flow inward in terms of revenue. The enterprise can earn some money \( \text{profit} = R - C \), where is the total cost sum that includes four parts: \( C_1 \) is salary and bonus; \( C_2 \) is maintenance costs; \( C_3 \) is training costs that occur when employees must acquire new skills; and \( C_4 \) is transaction costs for organizational adjustments to the changing of environment. As the organization adapts, each changed selection of organizational structure \( S \) has a certain performance score that is a function \( E(S) \), which maps every changed selection of a subset \( S \) to a real number \( E(S) = \text{Agility}(S) \) or \( \text{Robustness}(S) \) or \( \text{Resilience}(S) \) or \( \text{Survivability}(S) \), which is needed to maximize the following objective functions under the certain limitation of budget.

\[
\max_{S \subseteq V} \text{Agility}(S) \quad \text{and} \quad \max_{S \subseteq V} \text{Robustness}(S)
\]

\[
\max_{S \subseteq V} \text{Resilience}(S) \quad \text{and} \quad \max_{S \subseteq V} \text{Survivability}(S)
\]

subject to \( C(S) \leq B \) \hspace{1cm} (4)

where \( C(S) = \sum_{s \in S} c(s) \) is the total cost of the change selection \( S \).

Figure 3. The measurements of different dimensions of organizational adaptation

Figure 4. The black box business process of agile enterprise

We need to maximize the four objective functions in this model. However, this optimization is an ‘NP-completed’ problem and only an approximate solution for the selection of organizational structures that can be found. The fitness landscape of this solution space is rugged, and we initially shrink the search space, and then use simulated annealing to solve this problem [5]. The detailed steps are shown in the following algorithm:

1. \( S_i = S_0; \ T_E = T_{E0} \) // Initial state
2. while \( T_E > T_{E_{\text{min}}} \) // While temperature is still high
3. \( S_j = \text{neighbor}(S_i) \) // Randomly pick some neighbor
4. \( C = E(S_j) - E(S_i) \) // Compute its cost
5. if \( C <= 0 \) // Is this a new best?
6. \( S_b = S_j \) // Yes, save it
7. if \( \exp(-C/T_E) > \text{random}(0,1) \) // Should we move to it?
8. \( S_i = S_j \) // Yes, change state
9. \( T_E = T_E - \Delta T_E \) // Drop temperature
10. return \( S_b \) // Return the best solution found

The probability of accepting a new organizational structure is based on the Metropolis criteria [37]. According to this criteria the organization always accepts the change
if the resulting hypothetical organization is a better performer than the current one. Otherwise, the change is accepted with a probability given by \( \exp(-C/T) \).

### 4. Virtual Experiments Design

Agent-based modeling is a metaphor that is based on the characteristics and behaviors of the individuals, and establishes individual characteristics and behaviors in the model. The individuals are mapped as agents, individual characteristics as the attributes, and individual actions as the behaviors of the agent [38]. The agents will interact with each other to adapt to the change of environment. To discover insights about organizational adaptation from the simulation of interaction between organization and tasks, we use our model to run a series of virtual experiments [32]. The simulation model can be regarded as the test bed to alter parameters according to our requirements and to observe the resulting behaviors. From the findings of virtual experiments, potentially useful implications for practitioners can be revealed. As shown in Table 1, we design a series of virtual experiments in order to examine the Agility, Robustness, Resilience and Survivability of organizational adaptation. The different combinations of demand and supply inertia represent different communication cultures among workers. Specially, we focus on the three different conditions of communication: free trade, medium trade and no trade. In the condition of free trade (demand inertia = 1, supply inertia = 1), workers can communicate with each other very freely and do not have inertia between their interactions. In the condition of medium trade (demand inertia = 0.5, supply inertia = 0.5), workers faces some pressures to supply or demand help from other workers, and they should keep balance in the communication. In the condition of no trade (demand inertia = 0, supply inertia = 0), the culture is very dull, people do not communicate with each other, there is no chance to exchange the labors, and workers have the highest priority of finishing their own tasks (standing always in the same department and finishing the assignments from their manager). There are \( 3 \times 3 \times 5 = 45 \) (Table 1) conditions for the virtual experiments; we ran every virtual experiment independently for 100 runs by Monte Carlo simulation procedure [32]. During simulations, other parameters remain at their default values, as described in Appendix A.

### Table 1. Virtual experiments design of organizational structure change for adaptation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand inertia</td>
<td>0, 0.5, 1</td>
</tr>
<tr>
<td>Supply inertia</td>
<td>0, 0.5, 1</td>
</tr>
<tr>
<td>Max-hierarchy</td>
<td>1, 2, 3, 4, 5</td>
</tr>
</tbody>
</table>

### 5. Simulation Study by Virtual Experiments

We first run the simulations according to Table 1 under the different dimensions of organizational adaptation. Through simulations, we examine the genome of organizational structure (the value combination of max-hierarchy, demand-inertia and supply-inertia) of Agility, Robustness, Survivability, and Resilience of the organization (see Subsections 5.1, 5.2, 5.3, 5.4 respectively). Because every condition is needed to run independently for 100 repetitions, the presented results are the average cumulative balance of all the repetitions. We use sensitivity analysis to test the impacts of all the important parameters on the organizational profit and analyze the finding from the study of optimal genome on all the dimensions of organizational adaptation.

#### 5.1. The Genome of Agility

To examine the Agility dimension of organizational adaptation, we design two scenarios to represent the change of the internal and external environments respectively:

1. **Number of Workers** increase from 3 to 32 every 100 ticks (hire new employee gradually) and set the wave-breadth = 16 as a constant value when running the business. Other parameters are set according to default values.

2. **Wave-Breadth** increase from 16 to 32 every 100 ticks (the opportunities increase gradually) and set number of workers = 12 as a constant value when running the business. Other parameters are set according to default values.

The Agility is the average velocity that is equal to the final cumulative balance divided by the ticks period, we examine the impact of hierarchy level and communication (trade) on the Agility. The dynamics of the output result are shown in Figures 5 and 6. The correlation analysis results by SPSS are shown in Tables 2 and 3. The results are the average values of numerous independent Monte Carlo simulations.

### Table 2. The correlation analysis result by SPSS for Agility (internal environment)

<table>
<thead>
<tr>
<th></th>
<th>Demand-inertia</th>
<th>Supply-inertia</th>
<th>Max-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agility Pearson correlation</td>
<td>–0.478**</td>
<td>–0.458**</td>
<td>–0.298*</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.001</td>
<td>0.002</td>
<td>0.047</td>
</tr>
<tr>
<td>N</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
For the same setting of other parameters, under the conditions of ‘free trade’ and ‘medium trade’, the majority of balance curves increase after an initial small decrease process. However, under the ‘no trade’ condition, the balance curves decrease. Workers lack communication, and they act and exchange positions to adapt to the change of the internal environment according to their manager. The maintenance of hierarchy needs a large amount of cost (salary) to obtain the positive profit, so the cumulative balance is decreasing over time. By analysis of SPSS, we obtain the following results: under the change of the internal environment, demand-inertia and supply-inertia affect the Agility negatively and both strongly significantly, and the maximum level of hierarchy also affects the Agility negatively and weak significantly. Under the change of the external environment, demand-inertia and supply-inertia affect the Agility negatively and both strongly significantly, but the maximum level of hierarchy affects the Agility positively but not significantly.

In practice, in order to accommodate the quick change of internal and external environment, the enterprise needs to maintain a relatively flat organizational structure. More flexibility is needed by the managers on the low level, because these managers do not have a large span of control and they can guide the workers more carefully, and meanwhile the flat organizational structure can avoid the unnecessary transaction cost when communicating between the members in the hierarchy. However, a larger hierarchy can keep a more stable business running which prevents
bankruptcy in turbulent business environments. When the external environment is rapidly changing, enterprises need additional hierarchy to address attrition and more emphasis needs to be placed on communication. Demand-supply inertia should be minimized, and the free trade atmosphere information will flow smoothly to improve the quality of responding to environmental demands. In conclusion, flat organizational structure (lower hierarchy and smaller span of control) and flexible communication mechanisms (less demand-supply inertia) are significant to improve the organizational Agility.

5.2. The Genome of Robustness

To examine the Robustness of organizational adaptation, we designed a scenario that the wave-breadth of opportunities can change from 16 to 8 for one time cycle of 100 ticks, which represent the external environment change periodically. This scenario describes situations in which the sales environment changes according to the needs of the market, which usually changes periodically due to the ebb and flow of supply and demand. The number of workers remains at a constant value of 16 and the robustness is examined under different organizational structures (the combination of hierarchy, demand-inertia and supply-inertia). As shown in Figure 7, the curves with the legend ‘CH’ represent the scenarios of opportunities change (the wave-breadth of opportunity change from 16 to 8), and these scenarios compare to the other category of scenarios with the legend ‘CO’ (the wave-breadth of opportunity is a constant 16 for all the time). The Monte Carlo simulation results of the ‘CO’ scenario are expected output and its deviations between output results of ‘CH’ scenarios are organizational Robustness. The smaller deviation represents the higher Robustness.

The qualitative analysis shows that it is obvious that under the ‘free trade’ condition, the ‘CH’ scenarios are the closest to the expected ‘CO’ scenarios. Through further analysis by SPSS, we found that the maximum level of hierarchy also affects Robustness positively at the significance level of 0.05. Related to the communication culture, the supply inertia affects Robustness more significantly than demand inertia. Although, it is shown in Table 4 that demand inertia does affect Robustness negatively but not significantly.

In practice, more communication and more hierarchy mean that the organization is more robust. This conclusion has real-world implications: to appropriately respond to the change of environment, timely communication can improve the organizational ability of the risk-averse. The communication among workers needs to be spontaneous, but this communication must also be limited to achieving the unitive purpose generated by the manager in the hierarchy, if not this communication is counterproductive. Also, greater hierarchy centralization produces a larger span of control and the command transferred to workers is more authoritative and direct. In this way, the organization can avoid the information distortion that occurs during the process of transferring command across a broader, more decentralized hierarchy. In conclusion, the centralization (high hierarchy and large span of control) and flexible communication mechanism (less demand-supply inertia) are significant to improve the organizational Robustness.

<table>
<thead>
<tr>
<th>Table 4. The correlation analysis result by SPSS for Robustness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Supply-inertia</td>
</tr>
<tr>
<td>Pearson correlation</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>* Correlation is significant at the 0.05 level (2-tailed).</td>
</tr>
</tbody>
</table>
5.3. The Genome of Survivability

Assessment of survivability of the organization was based on financial viability which is measured by the bank balance over a time period of ticks. If the bank balance fell to, or below, zero then the organization did not survive, as it was out of business. If the organization maintained a positive bank balance throughout the time frame then it was designated robust for this study. The period duration is used to measure survivability. To examine this we designed two scenarios:

1. **Number of Workers** decreasing from 20 to 2 every 100 ticks (fire the employees gradually), which represents the change of internal environment. We keep the external opportunities environment unchanged (wave-breadth = 12).

2. **Wave-Breadth** decreasing from 16 to 2 every 100 ticks (the opportunities decrease gradually), which represents the change of the external environment. We keep the internal human resource environment unchanged (Number of Workers = 8). The dynamics of cumulative bank balance for the above two scenarios are shown in Figures 8 and 9 respectively.

The analysis result by SPSS in Table 5 and Table 6 shows that maximum level of hierarchy and supply, demand inertia affect survivability positively and strongly significantly despite the type of environmental change. Thus, the organization with more communication among workers and less hierarchy (smaller span of control) has stronger survivability. It is obvious that flexible communication and flat organizational structure allow organizations to survive longer.

5.4. The Genome of Resilience

To examine the Resilience of organizational adaptation, we also design two scenarios that are the same as Section 5.3. The first scenario (Figure 8) is used to examine the worker resilience to internal environmental change: how many persons can leave and the organization for it unchanged (Number of Workers = 8). The dynamics of cumulative bank balance for the above two scenarios are shown in Figures 8 and 9 respectively.
Table 5. The correlation analysis result by SPSS for Survivability (internal environment)

<table>
<thead>
<tr>
<th>Supply-inertia</th>
<th>Demand-inertia</th>
<th>Max-level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Survivability</strong></td>
<td><strong>Pearson correlation</strong></td>
<td><strong>Sig. (2-tailed)</strong></td>
</tr>
<tr>
<td>-0.492**</td>
<td>-0.503**</td>
<td>0.001</td>
</tr>
<tr>
<td>-0.134**</td>
<td>0.031</td>
<td>45</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed).**

Table 6. The correlation analysis result by SPSS for Survivability (external environment)

<table>
<thead>
<tr>
<th>Supply-inertia</th>
<th>Demand-inertia</th>
<th>Max-level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Survivability</strong></td>
<td><strong>Pearson correlation</strong></td>
<td><strong>Sig. (2-tailed)</strong></td>
</tr>
<tr>
<td>-0.434**</td>
<td>-0.484**</td>
<td>0.003</td>
</tr>
<tr>
<td>-0.254**</td>
<td>0.092</td>
<td>45</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed).**

still to be profitable and survive? The second scenario (Figure 9) is used to examine opportunities resilience to external environmental change: how much can the opportunities decrease and the organization still be profitable and survive? To calculate the resilience, we first smooth the curves and then find the inflection of the curve by calculating the gradients along it. The correlation analysis result by SPSS for worker resilience and opportunity resilience are shown in Tables 7 and 8 respectively. The analysis results show that demand, supply inertia and hierarchy all affect organizational resilience negatively and significantly, which means that more flexible communication and less hierarchy can improve the resilience of organizational adaptation. Also, it is shown that Resilience has positive and significant correlation with Survivability. It can prove that Resilience is the superset of survivability.

In practice, the flat organizational structure and flexible communication among workers allow the organization to withstand larger changes in the external and internal environments.

5.5. The Optimal Genome of Organizational Adaptation

We use the simulated annealing algorithm to maximize the objective function depicted in Section 3.3. As discussed in the previous section, besides improving Robustness, more flexible communication and lower hierarchy (smaller span of control) can promote the Agility, Resilience and Survivability of organizational adaptation. The optimal genome of organizational adaptation (Table 9) shows that in order to keep balance in the four dimensions of organizational adaptation, we need to maintain a flat organizational structure while allowing a certain level of centralized command when responding to the change of external and internal environments.

5.6. Sensitivity analysis

We evaluate the sensitivity of the organizational adaptation genome at a starting bank balance of $30,000 and three worker levels (8, 10 and 12). The parameter setting of sensitivity analysis is shown in Table 10. The starting locations of the workers were set at random. The average cumulative bank balance and average number of ticks were calculated for each test scenario over 10 iterations. Each individual run was stopped if the bank balance dropped to less than $0 or a total of 500 ticks were reached. The parameters setting refer to details in Appendix A.

Of the 196,608 permutations of genomes and environmental settings 20,230 survived the 500 ticks and were profitable. Statistical analysis is provided in Table 11. A closer examination of the top performers is contained in Table 12. All of the top performers had 12 workers, the maximum number that was tested. The most highly correlated setting is the Tmax value for the level 1 manager. This is negatively correlated which means that there is an inverse relationship between this value and whether the genome is successful. As a smaller Tmax value is better, this translates to a lower tolerance to penetrations. Downward inertia is the next highly correlated value, but positively. This means that the ease of dissolving the hierarchy contributes to the organization’s success.

6. Discussion

Our computational model is originally designed for the market/sales business organization, and marketplace Agility is very important to sales enterprises. However, it is not enough if we just consider marketplace Agility. The Robustness, Resilience and Survivability are also very important for sales organization being agile. Indeed, real-world companies might have a slightly different set of priorities than the ones described here. For instance, Survivability might be the most important for any company, since its first priority is to survive and compete. Robustness might also be much more highly prized, as companies must develop their own business over time, according to their own direction and vision for future development. How to minimize disturbances enables whether or not the organization is robust enough to persist. The third most important element can be Agility. Under the right developing direction and without concern for basic survival, the company can turn attention to agility of organizational adaptation. In today’s marketplace, the weak are falling...
AN AGENT-BASED SIMULATION STUDY FOR EXPLORING ORGANIZATIONAL ADAPTATION

Table 7. The correlation analysis result by SPSS for workers resilience

<table>
<thead>
<tr>
<th></th>
<th>Supply-inertia</th>
<th>Survivality</th>
<th>Demand-inertia</th>
<th>Max-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resilience</td>
<td>-0.336*</td>
<td>0.655**</td>
<td>-0.507**</td>
<td>-0.086</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.024</td>
<td>0.000</td>
<td>0.000</td>
<td>0.573</td>
</tr>
<tr>
<td>N</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 8. The correlation analysis result by SPSS for opportunities resilience

<table>
<thead>
<tr>
<th></th>
<th>Survivality</th>
<th>Supply-inertia</th>
<th>Demand-inertia</th>
<th>Max-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resilience</td>
<td>0.959**</td>
<td>-0.458**</td>
<td>-0.476**</td>
<td>-0.318*</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
<td>0.033</td>
</tr>
<tr>
<td>N</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

victim to the strong and competition is often severe. If a company cannot hold its market share, another competitor often moves in and causes the company to fail. Thus, responding quickly to changes of environment is necessary to capitalize on business opportunities and generate maximum profit. The last most important element of organizational adaptation is resilience. It is a tolerance test that is the ability for an organization to allow the disrupt change including human resource attrition and decreasing market (task) opportunities. Facing a disruptive change, an organization can still generate profit. This tolerance ability is a representation of resilience.

In this paper, we have selected span of control, hierarchy and communication to examine the centralization and configuration dimensions of organization structure [19]. Using simulation to study these two dimensions of organizational structure on the four dimensions of organizational adaptation is helpful to understand the essential intrinsic mechanism of organizations responding to the fast changing environment. Of course, our computational model is not limited to studying the sales organizations. The sales opportunities are tasks that labor workers need to execute, and these tasks can expand to other tasks in research-based knowledge teams, consultant teams and product teams.

Exploration of the problem space from a complex systems perspective reveals that much has been learned during the construction of a model while framing the problem. In our Netlogo model, we had the benefit of working from a well thought-out design. We gained an appreciation for the dynamics of how organizations operate and the effort it takes to produce a model. Epstein stressed that his model was not close to representing a real organization; by comparison it was fairly simplistic. The complexity increased as we expanded the model with our relatively minor enhancements. It is clear that it would be a significant effort to make the model more realistic where it could represent an actual organization. CEOs and the management team must have good heuristics and intuition to articulate the appropriate connections to be modeled.

Nevertheless, there were several limitations for our model. Our model was constrained by the size of the grid, which could be saturated by opportunities and workers. For example, if the grid was filled with workers in every available space, it would guarantee that all opportunities could be captured. Common sense tells us that it would be too expensive to hire that many workers, and that additional management would be required as the numbers scale. It would be interesting to explore the boundaries for the optimal number of workers.

Other explorations could involve cost of labor. Salaries in organizations are not static. In many companies there is a relationship between profitability and salaries. As

Table 9. The optimal genome of organizational adaptation

<table>
<thead>
<tr>
<th>Demand inertia</th>
<th>Supply inertia</th>
<th>Max-hierarchy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 10. The parameter setting of sensitivity analysis

<table>
<thead>
<tr>
<th></th>
<th>Starting value</th>
<th>Increment</th>
<th>Ending value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mgr1 Tmax</td>
<td>0.0</td>
<td>3.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Mgr2 Tmax</td>
<td>0.0</td>
<td>3.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Mgr3 Tmax</td>
<td>0.0</td>
<td>3.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Mgr4 Tmax</td>
<td>0.0</td>
<td>3.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Demand-inertia</td>
<td>0.0</td>
<td>0.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Supply-inertia</td>
<td>0.0</td>
<td>0.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Upward-inertia</td>
<td>0.0</td>
<td>3.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Downward-inertia</td>
<td>0.0</td>
<td>3.0</td>
<td>9.0</td>
</tr>
<tr>
<td>K</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

K = 0.5 for all runs
the company makes more money, it can afford to reward its employees. The model could be expanded to provide bonuses to workers and managers as the bank balance increases. Also, the cost structure could be expanded to provide yearly salary increases. This model did not factor in that other organizational changes impact operating costs. One example is employee attrition. Another example is the costs associated with collapsing the hierarchy as the organization adapts.

7. Conclusions

In this paper, we have expanded Epstein’s organizational adaptation computational model [14] to propose a new computation model to examine four dimensions of organizational adaptation: Robustness, Agility, Resilience, and Survivability. Using a Netlogo agent-based simulation platform, we ran Monte Carlo simulations on this computational model and designed six types of scenarios (Figures 5, 6, 7, 8, and 9) to run virtual experiments of examining the four dimensions of organizational adaptation. In addition, we used the simulated annealing algorithm to obtain the optimal organizational structure to keep balance in the four dimensions of organizational adaptation. Through simulation study, we concluded that besides improving Robustness, more flexible communication and lower hierarchy (smaller span of control) can promote the Agility, Resilience, and Survivability of organizational adaptation. That is, flat organizational structure and flexible communication mechanism (less demand-supply inertia) are significant to improve the organizational Agility, Resilience, and Survivability. However, for improving Robustness, the centralization (high hierarchy and large span of control) and flexible communication mechanism (less demand-supply inertia) are significant. Thus, in agile enterprise, the flat organizational structure and flexible communication is necessary, but meanwhile the organization needs to keep a suitable centralized command transferring structure to run the business under the right vision, strategic direction of organization designed to maintain ongoing competitiveness [36].

Our model is an agent-based simulation model, and the main objective is to help people understand the adaptation organizational structure. Actually, a computation model in the management field cannot be too complicated, because the main objective is to help people understand a certain issue in specified field. The design of computation model depends on what kind of questions authors want to answer and examine. In this paper, our model is based on Netlogo platform. This paper has provided virtual experiments to explore organizational adaptation, but it still has two key limitations. First, our computational model is a simple theoretical model that only includes at most 32 workers and five levels in an organization. Using this simple model, we can clearly examine organizational adaptation in four different dimensions. This model can be easily modified to test other issues in larger enterprises, and a Netlogo platform is easy to program so as to include other factors related to organizational adaptation. However, in this paper, our model has not supplied related interfaces for this programming extension. Second, our Netlogo-based computational model is a simulation model that does not include the data from real enterprises. If readers want to extend our platform to a larger organization and also want to use huge datasets in real organizations, you still need to change the design of this model to be scalable to the distributed computing environment. Also, the Netlogo platform would require a distributed deployment across a network.

In the future, the assumed equal workforce can be a variable that affects assigning resources and/or undertaking opportunities. We will also expand this work from a hierarchy structure to a network structure of organizations. In practice, the matrix management in enterprises is a type of social network between employees. Besides, we can include all aspects of the company into the network: employees have some relationships between each other; people have some skill, so individuals will relate

Table 11. The result of sensitivity analysis

<table>
<thead>
<tr>
<th></th>
<th>Mgr1-Tmax</th>
<th>Mgr2-Tmax</th>
<th>Mgr3-Tmax</th>
<th>Mgr4-Tmax</th>
<th>Upward inertia</th>
<th>Downward inertia</th>
<th>Supply inertia</th>
<th>Demand inertia</th>
<th>Num worker</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>4.10</td>
<td>5.91</td>
<td>4.92</td>
<td>4.58</td>
<td>12.91</td>
<td>7.50</td>
<td>0.76</td>
<td>0.86</td>
<td>11.54</td>
<td></td>
</tr>
<tr>
<td>Std Dev</td>
<td>3.80</td>
<td>3.10</td>
<td>3.31</td>
<td>3.34</td>
<td>2.83</td>
<td>5.58</td>
<td>0.18</td>
<td>0.10</td>
<td>0.84</td>
<td></td>
</tr>
<tr>
<td>Correl</td>
<td>0.12</td>
<td>-0.08</td>
<td>-0.13</td>
<td>-0.03</td>
<td>0.08</td>
<td>-0.01</td>
<td>0.15</td>
<td>0.23</td>
<td>0.16</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 12. The result for the sensitivity analysis of top 0.5% of survivors

<table>
<thead>
<tr>
<th></th>
<th>Mgr1-Tmax</th>
<th>Mgr2-Tmax</th>
<th>Mgr3-Tmax</th>
<th>Mgr4-Tmax</th>
<th>Upward inertia</th>
<th>Downward inertia</th>
<th>Supply inertia</th>
<th>Demand inertia</th>
<th>Num worker</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>6.85</td>
<td>4.96</td>
<td>5.15</td>
<td>4.52</td>
<td>12.89</td>
<td>7.47</td>
<td>0.89</td>
<td>0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std Dev</td>
<td>2.30</td>
<td>3.27</td>
<td>3.46</td>
<td>3.44</td>
<td>2.59</td>
<td>5.55</td>
<td>0.06</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correl</td>
<td>-0.58</td>
<td>-0.13</td>
<td>0.03</td>
<td>0.16</td>
<td>0.10</td>
<td>0.23</td>
<td>0.08</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
to skills too; tasks have their own schedules; individuals will be involved into the tasks. This network is not limited to humans and it is complex and dynamic. We can use network analysis methods and agent-based simulation to examine how to enable a suitable individual with the suitable skill allocated to the suitable task. Also, organizations have a great deal of empirical information (or human resource database) which would be helpful for constructing different kinds of networks in the research of organizational adaptation.

8. Acknowledgments

We specially thank Joshua Epstein for his lecture on Organizational Adaptability in the Santa Fe Institute’s 2008 Complex Systems Summer School. For valuable comments and discussions, we thank Brad Jones (Nativis, Inc.) and PersonName Brian Hirshman (CASOS, CMU). We also thank Shawn Barr for his hard work on the implementation of the original Netlogo Model. The authors gratefully acknowledge China Scholarship Council for providing scholarship for my visit to Carnegie Mellon University and CASOS – the Center for Computational Analysis of Social and Organizational Systems at Carnegie Mellon University which proved a good research and discussion environment. This work was funded by the China National Natural Science Fund (No. 70671048) and Hubei Province Sci. & Tech. Plan Important Project (No. 2007AA401B27). This work was also partially supported by the Santa Fe Institute whose research and education programs are supported by core funding from the US National Science Foundation and by gifts and grants from individuals, corporations, other foundations, and members of the Institute’s Business Network for Complex Systems Research. This work was also supported in part by the US National Science Foundation under Grants IIS 0755405 and CNS 0821585.

9. Appendix A: The Parameters of MARRS Model

1. Opportunity Generation:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layout</td>
<td>Provides five different options for specifying the dynamics of the opportu-</td>
</tr>
<tr>
<td></td>
<td>nity/threat stream generation.</td>
</tr>
<tr>
<td>Saw-Freq</td>
<td>Determines the frequency of the saw-tooth stream dynamics.</td>
</tr>
<tr>
<td>Wave-Breadth</td>
<td>Determines the breadth (and depth) of the opportunity stream.</td>
</tr>
<tr>
<td>Even-Column-</td>
<td>Determine the probability that an opportunity will be generated within</td>
</tr>
<tr>
<td>Probability</td>
<td>each defined location within the specified opportunity stream for even-</td>
</tr>
<tr>
<td></td>
<td>numbered stream columns.</td>
</tr>
</tbody>
</table>

2. Worker and Manager Parameters:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Workers</td>
<td>Determines the number of ‘workers’/‘teams’ that can be deployed to engage</td>
</tr>
<tr>
<td></td>
<td>the opportunities. If the maximum number (32) is specified then all</td>
</tr>
<tr>
<td></td>
<td>opportunities will be engaged.</td>
</tr>
<tr>
<td>Memory Length</td>
<td>Determines how long (how many ‘ticks’) a manager can remember what has</td>
</tr>
<tr>
<td></td>
<td>happened in the past.</td>
</tr>
<tr>
<td>Tmin</td>
<td>Determines the maximum percentage (%) of missed opportunities (averaged</td>
</tr>
<tr>
<td></td>
<td>over the specified memory-length) that will trigger Downward-inertia to</td>
</tr>
<tr>
<td></td>
<td>grow.</td>
</tr>
<tr>
<td>Tmax</td>
<td>Determines the minimum percentage (%) of missed opportunities (averaged</td>
</tr>
<tr>
<td></td>
<td>over the specified memory-length) that will trigger Upward-inertia to</td>
</tr>
<tr>
<td></td>
<td>grow.</td>
</tr>
<tr>
<td>Worker/Manager</td>
<td>Determines what the active workers and managers will be paid each tick.</td>
</tr>
<tr>
<td>Salaries</td>
<td></td>
</tr>
<tr>
<td>MidManager</td>
<td>Determines what a mid-level manager (one with a boss) is paid.</td>
</tr>
<tr>
<td>Salaries</td>
<td></td>
</tr>
</tbody>
</table>

3. Coordination Parameters:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand-</td>
<td>The willingness to ask for help from your trading partners. Ranges from 0</td>
</tr>
<tr>
<td>inertia</td>
<td>(never willing) to 1 (always willing).</td>
</tr>
<tr>
<td>Supply-</td>
<td>The willingness to provide help to your trading partners. Ranges from 0</td>
</tr>
<tr>
<td>inertia</td>
<td>(never willing) to 1 (always willing).</td>
</tr>
<tr>
<td>Upward-</td>
<td>Determines how many consecutive ‘ticks’ the maximum Threshold (Tmax)</td>
</tr>
<tr>
<td>inertia</td>
<td>must be met or exceeded before the manager starts trading and/or asking for</td>
</tr>
<tr>
<td></td>
<td>management support.</td>
</tr>
</tbody>
</table>

Volume 85, Number 6  SIMULATION  411
### Parameters

#### Downward-inertia
- Determines how many consecutive ‘ticks’ the minimum Threshold (Tmin) must fail to be meet before the manager must more surplus itself.

#### Max-hierarchy
- Determines how many levels of the hierarchy on maximum

### 4. Accounting Parameters:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downward-inertia</td>
<td>Determines how many consecutive ‘ticks’ the minimum Threshold (Tmin) must fail to be meet before the manager must more surplus itself.</td>
</tr>
<tr>
<td>Max-hierarchy</td>
<td>Determines how many levels of the hierarchy on maximum.</td>
</tr>
</tbody>
</table>

### 10. References


**Jiang Wu** is a PhD student in Huazhong University of Science and Technology, P.R.China. He received his M.S. from Tsinghua University, China. His interests focus on developing a social simulation model to study the coordination between information technology and organization.

**Bin Hu** is a Professor in the Management College and Director of the Institute of Intelligent Management and Complex System in Huazhong University of Science and Technology, P.R.China. He has a PhD in Management Science and Engineering from Huazhong University of Science and Technology (1999). His research interests include management system simulation, decision support system and artificial intelligence.

**Yu Zhang** is an Assistant Professor of Computer Science at Trinity University. She received a PhD in Computer Science from TAMU in 2005. Her general area of research is distributed multi-agent systems. Her research interests include intelligent agent and multi-agent systems, uncertainty in artificial intelligence, decision theory, machine learning, human–computer interaction, knowledge representation and modeling, and robotics automation and tele-operation.

**Catherine Spence** is an Enterprise Architect with Intel IT Research and Development, delivering research and studies to identify new technologies and methods which improve Intel business operations.

**Steven B. Hall** is a Principle Scientist at Lockheed Martin’s Advanced Technology Center focused on the development of technologies supporting system of systems design and analysis.

**Kathleen M. Carley** is a Professor of Computer Science in the Institute of Software Research at Carnegie Mellon University, Director of the Center for Computational Analysis of Social and Organizational Systems (CASOS), and founding co-editor of the journal Computational and Mathematical Organization Theory. Her research combines cognitive science, organizational theory, social and dynamic networks and computer science to address complex social and organizational problems involving adaptation, evolution, telecommunication technologies, information diffusion, disease contagion and performance. She has developed many multi-agent simulation systems such as BioWar and Construct and tools for analyzing large-scale dynamic networks including ORA and AutoMap for extracting networks from texts. She has co-edited several books and hundreds of articles in the computational organizations and dynamic network area.