Modeling Uncertainty through Agent-Based Participatory Simulation: Implication to Businesses in China

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China is a society that fosters complex social networks and they are considered powerful advantage in times of uncertainty. This article proposes agent-based modeling and simulation (ABMS) as a useful tool to analyze such complex relationships in China. It also reviews schools of thought on hard versus soft systems methodologies and brings together the fragmented literature on the nature of agent-based modeling, making the argument that participatory simulation is a distinct tool belonging to soft systems methodology, one which can simultaneously allow for the metrics of 'hard' decision sciences to be applied. This is a promising area of research in complex and highly dynamic systems and is particularly relevant to a country such as China due to its complexity and size.

INTRODUCTION

China, together with some other Asian countries, is a country where people view an object in a context and not in isolation of other objects that surround it. Hence, in Chinese society, relationship ('Guanxi') with other people is considered to be very important before one person's ability in isolation. Zhang and Neelankavil (1997) found that emphasizing the collective benefits of people is more effective in China than the US and this should be an important factor for such studies and their wide-reaching impact on society. Running a business in China is no exception. Knowing people and having a good relationship with them is crucial in marketing in China.

Participatory simulation lends itself to helping understand dynamic systems where complex human patterns of '*Guanxi'* in the Chinese content are particularly significant. It is more readily adopted where the collective benefits to society are paramount, such as in the prevailing culture of China. The purpose of this paper is to examine how 'soft' systems methodology may use agent-based modeling and simulation (ABMS) as a tool to better explore the problems of modeling uncertainty while combining rational decision analysis from 'hard' system methodologies and also to demonstrate how much ABMS can contribute to modeling 'Guanxi' in businesses in China. We argue that *participatory simulation* should be recognized as a distinct tool important to modeling some complex service systems like doing business in China, particularly under the conditions of disruption. While familiar to the context of training, the research opportunities associated with participatory simulation has yet to be fully explored.

The next section of this paper discusses 'hard' versus 'soft' system methodologies before considering the emergence of ABMS in operations research. While AMBS shows great promise, it is currently perceived as a new hard system methodology, where we argue that it shows equal potential as a soft systems tool. This potential and its relationship to participatory simulation together with managerial implications to China marketing are then discussed in the final sections of this paper.

HARD VS. SOFT SYSTEMS METHODOLOGIES

Hard systems methodologies are technology-centered and make the assumption that there is an optimal design for a scenario and that it is possible to reach this optimal solution through a process of analysis. Any people involved in the scenario are viewed as consistent elements which always perform in a predictable and rational way (Oura and Kijima, 2002). Hard methodologies such as linear and integer programming and development of information systems harnessing these tools comprise the oldest branch of operations research (OR), traceable back to the Second World War. At the heart of these approaches is the so-called "waterfall method," where an analysis is divided into distinct phases with specific descriptions of the tasks in each phase.

Once the analytical process is complete for one phase it moves to the next, never going back to the previous phase. Hard methodologies accumulated criticism over time for a lack of flexibility created by such linear thinking, and hence a number of newer alternatives were developed to substitute or supplement waterfall methodology, such as computer-aided systems engineering (Robinson, 1992), rapid application/systems development (Whitten *et al*., 2004), and joint application design (Purvis and Sambamurthy, 1997). These more iterative methodologies share the positivist view of information systems but differ from waterfall methodology by explicitly recognizing the role of people in the solution process and offering greater integration of their contributions.

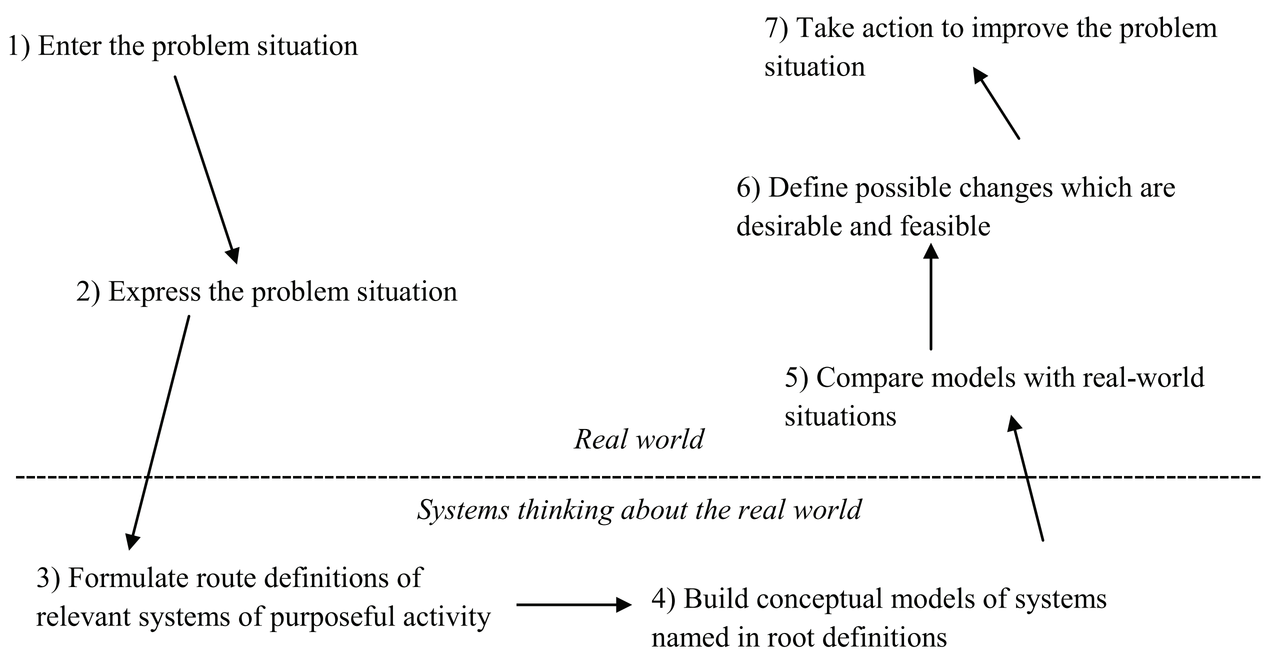
Nonetheless, these newer approaches remain 'hard' at the center, and critics of these methods argue that all technology-centered approaches are fundamentally insufficient for complex real-world problem solving, particularly when the situation is ill-structured or when political and cultural factors are prevalent (Checkland, 2001).

Soft systems methodology (SSM) were developed from hard systems engineering approaches to avoid the reductionism of natural science and to analyze complex situations where there are differing views regarding how to solve a business problem. This is typically conducted through a process of inquiry into problem situations of human affairs and as such the methodology does not seek an optimal solution, as many equal solutions may exist. SSM explore the complexity and confusion of the perceived versus the real world through a process of inquiry, with the objective of meeting the needs of various stakeholders.

SSM was set up as a seven step (Figure 1) interrogative process to engender debate amongst the relevant parties (Checkland, 1983), started by taking a particular view of the system, then incorporating subjective and objective impressions to form a rich picture of the system and then form a route definition of the problem. This eventually leads to the modeling of the human activity systems then considered relevant to the problem under review (Checkland, 2001).

As the decision-makers explore the problem in this way (the stages are not necessarily linear), a number of feasible options will present themselves to enable system improvements. The general applicability of this methodology is the reason for its success and widespread use (Checkland, 2001). Critics argue that SSM is functionalist and lacks theoretical rigor in that it is difficult to apply explicit evaluative criteria to assess the success of the SSM methodology; however, it remains the most widely used and practical application of systems thinking (Connell, 2001). SSM recognizes the importance of human (soft) factors in organizations and systems and the role of incremental learning; therefore, the role of SSM is to better capture and incorporate these relatively elusive elements of systems analysis rather than dismantling the system as advocated by hard systems thinking.

FIGURE 1
SOFT SYSTEMS METHOD BASIC FRAMEWORK



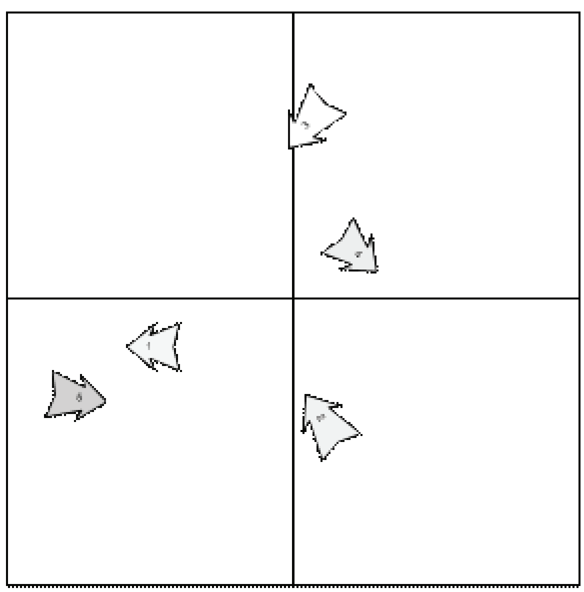
It would be wrong to think that hard and soft systems methods have completely diverged. Examples exist where the two methodologies have worked synergistically, such as the SISTeM methodology, where the first cycle follows that of SSM methodology and the second cycle that of hard decision analysis (Atkinson, 2000), or in the instance of Oura and Kijima (2002) where SSM is integrated into a waterfall approach. This may be viewed as the use of hard systems analysis tools during the investigation into a particular problem which may also help overcome the shortcoming, of lack of rigor, levied at SSM. Within the SSM it is the tools that may be drawn upon to help investigate the problem under review that are as crucial as the methodology itself.

What particular SSM tools are employed is often specific to the complex problem at hand and as such many have been developed or brought in from diverse fields such as Social Network Analysis from Sociology (Hancock & Raeside, 2010). It is one of the most promising of these 'borrowed' tools that is the focus of this article - agent-based modeling and particularly a distinctly under-utilized subset of that field described as participatory simulation. Participatory simulation may be at the cornerstone in the research methodology for studying large complex organizations, particularly in times of disruption (natural or man-made disaster), where often the *Guanxi*, the dynamic and personalized influence, on the system is little understood. This *Guanxi* characteristic (Lee & Dawes, 2006) of Chinese culture (Hofstede, 1984) makes participatory simulation particularly useful in studying dynamic systems of people in China. Before considering this point further, we must first discuss the emergence of agent based modeling and where it stands within hard and soft systems thinking.

THE EMERGENCE OF AGENT-BASED MODELING AND SIMULATION (ABMS)

An agent-based model is a computational model that simulates the actions and interactions of individuals to assess their impact on the overall complex system being researched. The individuals in the system operate within their own bounded rationality, and as a consequence of their actions at a micro level, the macro level system can be seen to emerge from the adaptations of individuals. Figure 2 provides a simple example, in which five agents are distributed at random across a space, moving at equal speeds in random directions.

FIGURE 2
SIMPLE AGENT-BASED SIMULATION:
INITIAL RANDOM DISTRIBUTION OF FIVE AGENTS



While no central design, cooperation or even communication is shared by the five agents, each agent follows a single decision rule based on local information: at the end of an iteration, the agent adjusts its orientation to the average of its original direction, and the directions observed as taken by its two closest neighbors. Figure 3 displays the result of the first such adjustment made by each member of the group, and Figure 4 displays the group after four iterations. Finally, after the sixth iteration as displayed in Figure 5, a coherent formation emerges, one which suggests design and central direction when in fact the starting positions were random and no explicit coordination exists.

FIGURE 3
SIMPLE AGENT-BASED SIMULATION: END OF FIRST ITERATION

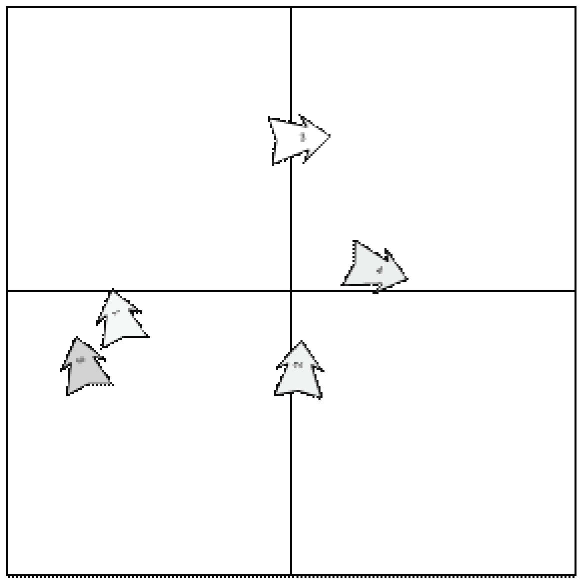
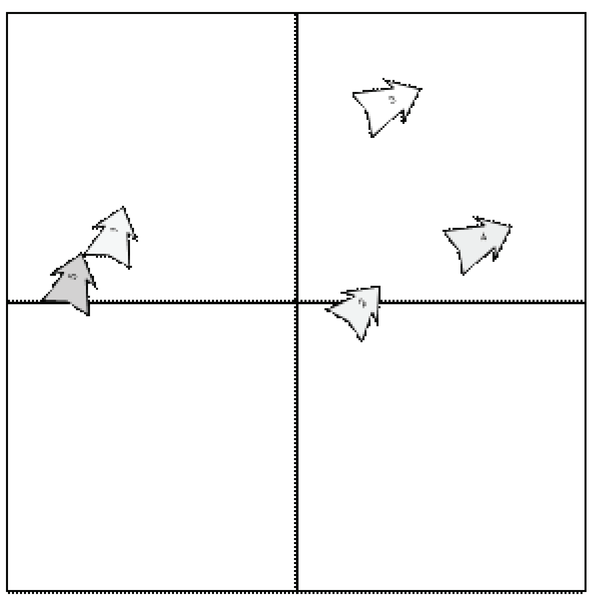


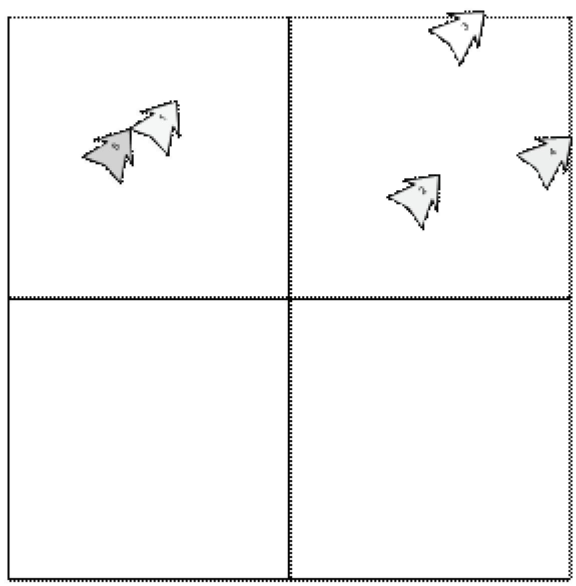
FIGURE 4
SIMPLE AGENT-BASED SIMULATION: END OF FOURTH ITERATION



In general, ABMS may combine elements from fields such as game theory, computational sociology, complex systems and emergence, often using Monte Carlo statistical methods to represent randomness. The majority of computational modeling research considers systems in, or moving to, an equilibrium/optimum state such as suggested by Figure 5; however, even simple rules and algorithms embedded in agent-based models can result in significantly more complex and counter-intuitive outcomes.

Thus, agent-based modeling and simulation (ABMS) is a promising growth area in operations research, stressing the representation of systems as sets of autonomous agents, each behaving and interacting according to locally available information. In contrast to traditional 'top-down' system dynamics, agent-based models render outcomes and system structures as emerging 'from the ground up' through these interactions (Macal and North, 2006). This conceptual approach is already assisting in the development of applications as varied as improved models of financial markets to re-creation of the growth and decline of ancient civilizations.

FIGURE 5
SIMPLE AGENT-BASED SIMULATION: END OF SIXTH ITERATION

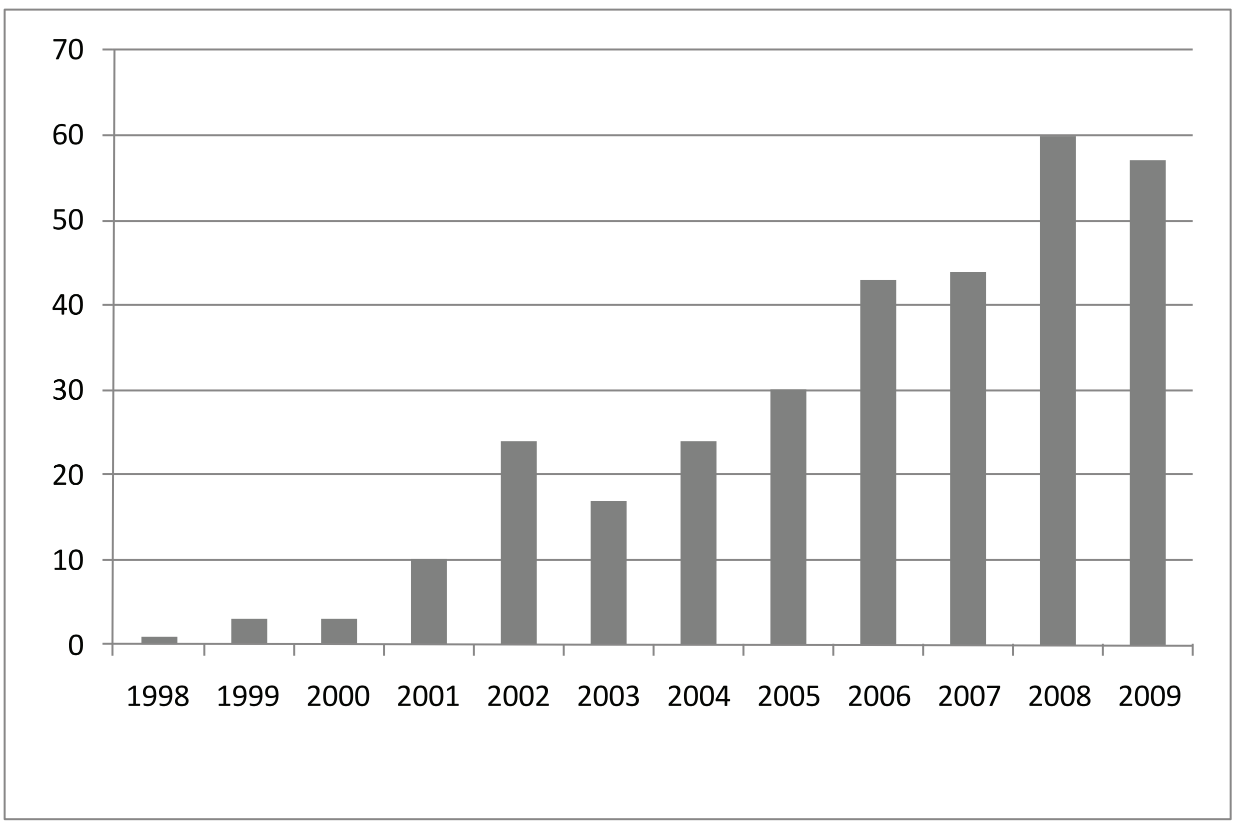


Ironically, this concept of an agent-based model was first developed in the 1940's; however, due to technological restrictions, it did not become prevalent until the 1990's. Much of the focus of interest during the 1990's and 2000's was on modeling the outcome of organizational effectiveness such explored by Samuelson (2000), Bonabeau (2002), or Sun (2006). Other recent OR applications of ABMS have explored issues such as transportation (Liedtke, 2009; Benenson *et al*, 2008), supplier selection (Valluri and Croson, 2005), and designing for organizational resilience (Siggelkow and Rivkin, 2005). While initial agent-based studies in other disciplines appear decades earlier, ABMS has caught the attention of OR/MS somewhat more recently, as evidenced by the increasing number of related publications, such as those tallied in Figure 6.

ABMS: HARD VERSUS SOFT METHODOLOGY?

In current operations literature, agent-based modeling generally complements many of the traditional 'hard' methods of analysis, particularly where such analytic methods allow the characterization of an equilibrium/optimal position. When an agent-based computational simulation readily exhibits and confirms those equilibrium/optimal positions identified by a 'Hard' OR approach, the result is typically considered a mainstream contribution. These computational models may also provide new insight into system robustness, demonstrating how a system made up of diverse individuals and their decisions interacting in a changing environment then adapts to various internal and external stimuli. It is important to note, however, that the vast majority of the research efforts suggested by the rising number of publications displayed in Figure 6 nonetheless rely on characterizing all human interaction as programmed elements, creating a wholly computational model consistent with the 'hard methodology' view of the environment.

FIGURE 6
NUMBER OF OR/MS JOURNAL ARTICLES WITH 'AGENT-BASED' IDENTIFIED AS TOPIC IN *WEB OF SCIENCE* DATABASE.



Taking the broadest view of ABMS, it is not difficult to see that many industrial systems and sectors are best described as agent-based, exhibiting outcomes highly dependent on the interaction of multiple autonomous decision-makers. In complex service systems, these internal agents often differ in capabilities and information available, and operate in highly dynamic environments that defy reliable scripting of all action and interaction in advance. Examples include some rapid industrial changeovers such as aircraft turn-around, emergency medical interventions, or incident and event management. The authors therefore propose that ABMS will prove crucial in the near future to furthering the understanding of such systems, particularly those that:

- incorporate multiple autonomous decision-makers within the service process;
- operate in highly dynamic, disorganized and/or turbulent environments;
- respond to unscheduled demands and/or have no control over elements of their system;
- are driven by both the actions and interactions of individuals; and
- are particularly reliant on situational awareness to derive good outcomes.

However, ABMS cannot create the best representations of such problematic instances if we continue to view it exclusively as a hard methodology. ABMS has established itself in OR through the Hard decision sciences where the majority of actors are played by computer 'bots' utilizing algorithms and heuristics (Liedtke, 2009) to determine their interaction with the human actors within a virtual environment. The main limitation of these studies is that actors do not often behave like computer 'bots', as replication of human behavior is problematic at best. The development of computer technology into massively multiplayer online role-playing games (MMORG), where large numbers of actors may interact with one-another within a virtual world, has led to previously unexplored opportunities for OR. Using the virtual world from Hard systems decision theory and supplementing that with the Soft element - by adding actual people into the virtual world, then the existing limitations of Hard systems decision science can be mostly overcome.

PARTICIPATORY SIMULATION

Participatory simulation, in which *authentic* subject matter experts are embedded in an analogy, is an approach largely overlooked in OR/MS (Simpson and Hancock, 2009), but one which we postulate holds the greatest potential for progress in the understanding of complex and disorganized service environments.

One limitation common to emerging 'Hard' ABMS studies is the assumption that an agent must be rendered synthetically for the modeling study to proceed. Thus, all possible reactions and interactions of the agent, including nuances such as cognitive load and emotion, must be coded as a series of algorithmic decision rules for implementation by a computer. Furthermore, the distinction between information available to an agent and information *perceived* must be synthesized, a disparity of significance in rapidly evolving and disorganized settings. Participatory simulations, such as table-top exercises or multi-player virtual reality environments, circumvent this limitation by allowing human agents to effectively model these issues through authentic behavior.

Conventional approaches to truly unstructured problems have proven the most difficult area in OR and consequently this area is the least researched. The most notable efforts to overcome this gap, and the difficulties posed by these mostly practical problems, such as those of an incident commander, have come from the use of table-top simulation training exercises. Although seldom used in research (Simpson and Hancock, 2009) these table-top simulations are usually conducted for decision makers in dynamic situations. Hard OR offers programming computer 'bots' in simulation, however, this is entirely inappropriate for truly dynamic decision making where even the nature of the problem is often unclear. Additionally, it takes away the essence of people interaction and issues with communication and stress, and consequently, has never been successfully used in 'solving' unstructured problems. It is therefore in the area of disorganization, an OR area that has historically been poorly researched, that participatory simulation is particularly suited.

Participatory simulation utilizes real people in the simulation model thereby incorporating the Soft elements of the environment and bringing the wealth of research from the social sciences that has previously been absent in ABMS. Simultaneously it is open to utilize many of the Hard decision science evaluation metrics already developed, as it was born from Hard systems. Simulations may be designed in the same manner as existing Hard system studies, utilizing techniques such as, Statistical Process Control and many of the other quantitative techniques commonly used in Six Sigma and Process Engineering. It is this synergy of quantitative and qualitative techniques and tools that offers the greatest potential advances in OR.

To underscore the promise of participatory simulation is a specific research project that the authors are involved in: a senior team at the US Erie County Medical Center (ECMC) has been working for over one year on re-creating this emergency hospital in the MMORG virtual world. To date the hospital has been recreated virtually, designed to the actual building plans, with equipment (heart-rate monitors etc) that are in the process of being scripted to perform their 'real-life' function by people known as 'avatars'. A simulation where medical doctors act as themselves through an avatar, as do nurses and potential patients, within the virtual hospital negates many of the deleterious impacts of conducting a 'live' exercise, in that the hospital is not disrupted. Not only that, but research into areas such as mass casualty events may be constructed, for example modeling the 'bird flu' outbreak that Toronto hospital experienced in 2003. This research has both significant promises in practice and for academic research.

CONCLUSION AND MANAGERIAL SUGGESTIONS

Traditionally, hard systems methodology in ABMS, such as using computer 'bots' to approximate human behavior, has proven very limited for simulating complex interactions within large groups of people. Participatory simulation is a tool within soft systems methodology that combines personal and cultural dynamics with the rigor of hard systems thinking. Participatory simulation can also utilize relatively new technology (MMORG) for researching complex systems where multiple people are the decision makers.

Pilot projects are currently being developed using participatory simulation, such as the one the authors are involved with, to model dynamic personal networks in complex environments. MMORG technology requires the participation of many to achieve a collective outcome, and thus is uniquely suited to modeling systems set in the context of societies such as China, which emphasize collective good and utilize complex informal networks of personal interaction such as the dynamics of '*guanxi*.'

Guanxi would be virtually impossible to model in a hard methodology sense, yet cultures that foster these complex social networks often possess a powerful advantage in times of disruption and uncertainty, as good guanxi may produce a swift resolution to an unexpected problem where the formal methodology provided no answers. Participatory simulation could allow researchers and practitioners in China to better understand the possible applications of these intrinsic agent-based interactions and outcomes, potentially leaping China to the forefront of systems agility and resilience.

There are bountiful marketing applications in China, as agent-based models better explain the robust dynamics of "viral" message campaigns involving very large populations. The country that builds greater resilience into its complex human systems has a significant competitive advantage in world trade when unexpected events unfold, and agent-based participatory modeling offers new tools that pursue such advantages.

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