T. Terano, H. Kita, T. Kaneda, K. Arai, H. Deguchi, eds.
Agent-Based Simulation: From Modeling Methodologies to Real-World Applications
Springer Verlag Tokyo 2005

Grounded Theory and Multi-Agent Simulation for a Small Firm

Clinton J. Andrews, Ana I. Baptista, and Shawn L.W. Patton

Edward J. Bloustein School of Planning and Public Policy, Rutgers University, 33 Livingston Ave #302, New Brunswick, New Jersey, 08901, USA

Summary. There is a problematic disconnection in much research on organizational behavior between empirical evidence, mostly from case studies, and theorizing, most of which has been discursive rather than formal. This paper presents an empirically based, bottom-up view of organizational behavior, obtained by performing case studies of small firms in the New Jersey plastic injection molding industry, and then developing a multi-agent simulation model of such a firm. The model embodies a formal, explicit, and grounded (limited) theory of organizational behavior. Results suggest that a realistic account of corporate behavior depends in part on representing employees not as *homo economicus* but as agents having bounded rationality and subject to social influences.

Key words. Multi-agent simulation, grounded theory, organizational behavior, plastics

Introduction

The objective of this research is to test the efficacy of multi-agent simulation modeling for supporting grounded theorizing, that is, for developing theory by generalizing in a limited way from empirical evidence. This paper describes a research project that investigates organizational behavior through an iterative process of interviewing managers at small firms, developing narrative case studies of these firms, translating key elements of the case studies into a multi-agent simulation model, and then reviewing the modeling results with our original respondents.

Scientific understanding advances through the iterative actions of numerous individual researchers. Within a scientific community, deductive science connects theory to evidence with hypothesis testing (Popper, 1968), whereas inductive science connects evidence to theory with pattern matching (Tukey, 1970). And so the "wheel of science" spins forward, as evidence informs theory and theory guides the acquisition of new evidence (Wallace, 1971).

In the social scientific study of organizational behavior, where much data is qualitative, there are special challenges for making the wheel of science spin.

Hypothesis testing is notoriously difficult because variables are so interdependent that unidirectional assumptions of cause and effect are implausible. Pattern matching is equally difficult because many rival theories may equally well explain the typically very limited or even anecdotal data. As a result, there are many competing theories of organizational behavior and there is little convergence on empirically agreed "facts." Many of these explanatory theories have prescriptive counterparts that are championed by rival management gurus, resulting in continuing competition for mind-share rather than paradigmatic successions.

Grounded theory

One solution to this social scientific problem has been to define a humbler role for theory that recognizes severe limits to its generality. Grounded theory is such an approach. Like other inductive approaches, it means theory derived from data, systematically gathered and analyzed through the research process (Strauss and Corbin, 1998). In this particular method, data collection, analysis, and eventual theory stand in close relationship to one another (Glaser and Strauss, 1967). The researcher begins with an area of study and allows the theory to emerge from the data. One of the principal benefits of using the grounded theory approach is that it is closer to reality. Theories are drawn from data so they can offer insight, enhance understanding and provide a meaningful guide to action grounded in that same reality.

Thus grounded theory begins with a research situation. Within that situation, the task for the researcher is to understand what is happening there, and how the players manage their roles. A researcher will mostly do this through observation, conversation and interview. What most differentiates grounded theory from much other research is that it is explicitly emergent. It does not test a hypothesis. The aim, as its originator states it, is to discover the theory implicit in the data. This distinction between "emergence and forcing", as Glaser (1992) frames it, is fundamental to understanding how the methodology distinguishes itself from hypothesis testing. Constant comparison is the heart of the process. At first one compares interview (or other data) to interview (or other data). Theory emerges quickly in the form of crude classifications. When those have begun to emerge one compares further data to the theory. The researcher's task is to identify both categories (roughly equivalent to themes or variables) and their properties (in effect their sub-categories). In this way both methodology and theory develop gradually as data and interpretations accumulate. Eventually it becomes necessary to delimit the theory by ignoring categories deemed irrelevant to the inquiry. Finally, the theory must be written down, because the act of successfully communicating the theory greatly refines it. Grounded theory has its own sources of rigor (Glaser, 1992):

- It is responsive to the situation in which the research is done.

- There is a continuing search for evidence that disconfirms the emerging theory.
- It is driven by the data in such a way that the final shape of the theory is likely to provide a good fit to the situation.

Strauss and Corbin (1992) recommend that researchers develop grounded theory using a "memoing" technique that produces code notes, theoretical notes, operational notes. Lofland and Lofland (1995) advance the technique by recommending elemental analytical memos, sorting memos, and integrating memos. Babbie (2003; 379) urges researchers to write notes that "describe and define concepts, deal with methodological issues, or offer initial theoretical formulations." This paper takes the additional step of writing computer code to make the emerging theory even more highly explicit. The simulation model substantially extends the "memo."

Case study design and protocol

A case study research design was utilized to explore the questions of how social networks, both formal and informal, influence workplace behavior or business strategies of firms. A multiple case, replication design was used in which three cases or firms were studied (Yin, 2003). Firms were selected based on replication logic selecting three similar plastics processing firms in New Jersey of small to medium size. These particular firms were also selected because their manufacturing processes and organizational structure were simple relative to larger multinational firms and therefore would serve as a good starting point from which to begin to build a basic computer model.

The data collection protocol included several methods for each case:
(1) Elite, semi-structured interviews with firm executives or presidents
(2) Document analysis of financial, technical and environmental data
(3) Field visit, tours of plant operations

Access to each firm was garnered with the aid of an industry consultant familiar with many of the plastic injection molding and extruding firms in New Jersey. Confidential interviews with each firm were conducted, each was taped with the permission of the interviewee. The interview guide can be found on the project website shown at the end of this paper. Documents for analysis included company annual reports, company websites, industry wide websites, organizational charts, and U.S. EPA toxic release inventory website, newspaper and trade magazine articles. Individual case reports were created for each firm that included data from all three data collection methods. A cross case report was then developed with an overview of the project and analysis of cross case findings.

Case study findings

We expected to find that traditional family run firms would have more prominent social networks in which informal relationships hold great importance relative to more formal structures within a firm. Using company sponsored social activities as one indicator of the strength of social/informal networks within each company the cases revealed an interesting pattern. Company 1 and 2, both family run businesses that experienced a generational transition in leadership from fathers to sons, experienced a decrease in the number of company sponsored activities. These generational shifts also occurred at the same time as market shifts in the plastics industry with increased competitiveness resulting from new Asian competitors. Interestingly, Company 3, which is a similar establishment in size and technological terms but is not a family-run business, offers more company sponsored social activities than the family run companies. Company 3, unlike the other companies, is a subsidiary of a large multinational firm and has access to a wide variety of resources. This difference in the level of company-sponsored programs suggests that it is not just the familial nature of a company but rather the financial stability of the firm that matters a great deal in terms of supporting informal, social activities.

Another factor contributing to a change in the nature of social relationships within firms is the drive towards automation. Increased competition from Asia is pressuring firms to reduce costs, primarily labor costs. All three firms spoke about streamlining low skill jobs. At the same time, this streamlining process is putting increased emphasis on the quality of remaining employees. The interviews with all three companies revealed that the firms have a stable workforce characterized by low turnover and long-term employees. Loyalty to the firm, competence, and interest in the business are all highly sought after qualities in employees, which the firm in turn rewards with internal promotions. The importance of informal networks is also revealed in the "totem pole" hierarchy established by long-term employees. Within this informal hierarchy, seniority or tenure on the job is more important than professional or academic credentials. This accumulated job knowledge also forms the basis of internal promotional practices.

Another aspect of the business in which informal networks seem to play a key role is in the recruitment practices of all three firms. The majority of entry-level employees are of similar ethnic and cultural backgrounds; many are family members or reside in the same towns. These employees are mostly of Hispanic origin and they were brought into the firm via "word of mouth" practices with no formal recruitment practices in place. Company 3, unlike the firms, had a much stronger corporate culture in place than the family run firms, evidenced by their more stringent adherence to corporate principles, rules and regulations. Interestingly though, Company 3 still relied heavily on informal knowledge on the factory floor to improve its safety practices in particular. In order to improve safety, the company went beyond basic formal training and procedures and encouraged employees to make suggestions on the floor via a suggestion box and also as part of a committee. The head of the company also recognized the value of

bringing knowledge from outside the firm to bear on the issue of workplace safety. Ultimately, the drive towards automation coupled with the market shift to Asian companies (away from traditional U.S.-based family run businesses) appears to mean a decrease in the overall importance of social networks within these firms.

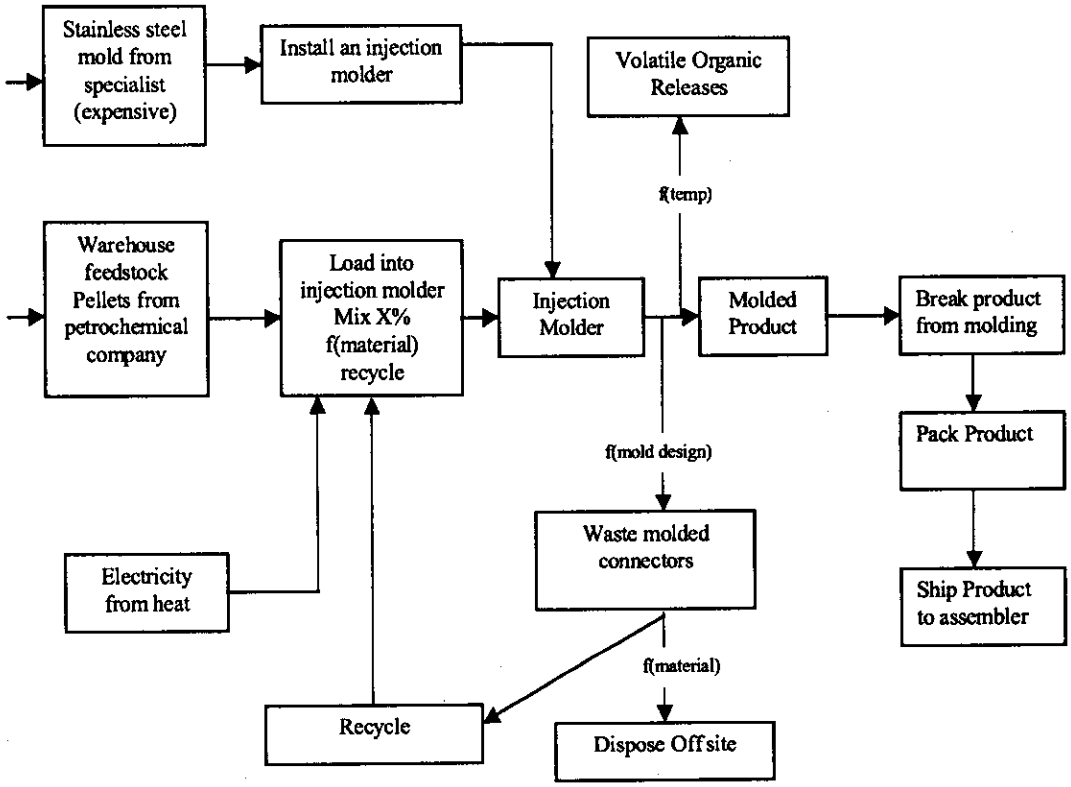

Fig. 1. Plastic injection molding process.

Model-building activity

Researchers often productively induct theory from case studies that, like good computer programs, are parsimonious and logically coherent (Eisenhardt, 1989). Parsimony was a goal of the modeling effort, and logical coherence was a handy byproduct of the debugging process. The dual challenges with any type of modeling are to simplify reality appropriately and to communicate the results effectively (Andrews, 2002). Both challenges proved significant during the modeling process.

Using the Brookings Institution's Ascape multi-agent simulation framework, a Java programmer created PolyModel, a simulation of operations at a plastic

injection-molding firm. Approximately 100 employees interacted with the production technology and one another, subject to changes in the firm's external environment. The model included technology details, organizational structures, and parameter values taken from Firm 1 in the case study. The model tested alternative theoretical constructs explaining the behavior of employees, to be roughly validated against the evidence from case study Firms 2 and 3.

Version 1.0 of the model includes 22 classes, related as follows. Figures 2 through 8 provide additional details.

PolyModel contains People, the Factory, and the External Environment.

The Factory includes a Warehouse, Production Lines, and a Shipping Department.

Employee extends Person.

Owner, Plant Manager, Marketer, Engineer, Shift Supervisor, Shipping Clerk, Materials Mixer, Maintenance Technician, Machine Operator, and Janitor all extend Job. Each Employee has a Job.

Remaining Java classes serve as computational infrastructure.

The time step in the model is hourly, so the firm cycles through the work day and the work week over a period of years. Each employee assesses whether to go to work every morning, based on health, social pressures, and finances. The plant manager determines how many production lines and associated employees are needed based on pending orders for widgets. The marketer brings in orders and tries to keep ahead of production so that the capacity factor of the plant is high. The janitor keeps the factory clean, and other employees become unhappy if the factory gets dirty. The materials mixer ensures that raw materials reach the production lines, and the shipping clerk packages completed products and sends them out the door. The maintenance technician keeps the production lines in working order. The machine operators perform several sequential duties (load plastic pellets, set molder temperature, separate widgets from scrap plastic). The shift supervisor encourages machine operators to work more carefully and reports on employee performance to the plant manager.

All employees are subject to worker error that affects the quality of their performance, and the probability that error will occur is a function of aptitude, experience, tiredness, and happiness. Worker Error impacts most stages of the production line. Higher worker error results in mistakes that cost the factory profits and increased waste which contributes to greater pollution.

Happiness, the lack of which contributes to worker error, is a weighted additive function of wealth and social embeddedness. Moneygrubbers like wealth (90, 10), Socialanimals like their friends (10/90), and TheRestofUs are more balanced (50, 50). Wealth increases by getting paid at work, social embeddedness increases by making more friends at work and elsewhere. Friendship depends on affinity (similar intrinsic characteristics) and frequency of interaction.

The dynamics of these employee interactions provide realistic drama and aggregate up to firm-level performance measures of interest to management.

Parameters are adjustable on the fly, and various diagnostic tools allow the user to investigate the causes of particular dynamic behaviors.

Developing the model required intense interaction between the programmer and the qualitative researchers. Much conversation centered on eliciting precisely what was the theory being formalized in the model. As the researchers played with the resulting simulations, the theoretical framework evolved.

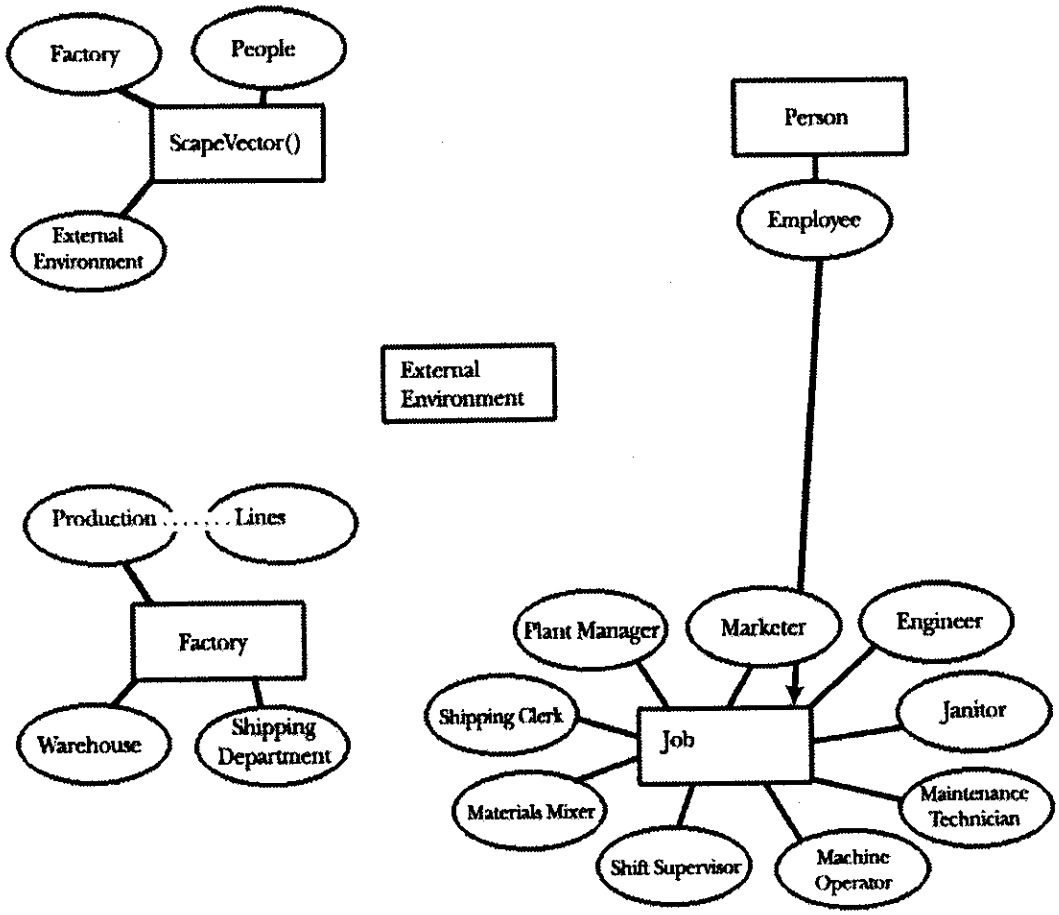

Fig. 2. PolyModel structures and agents.

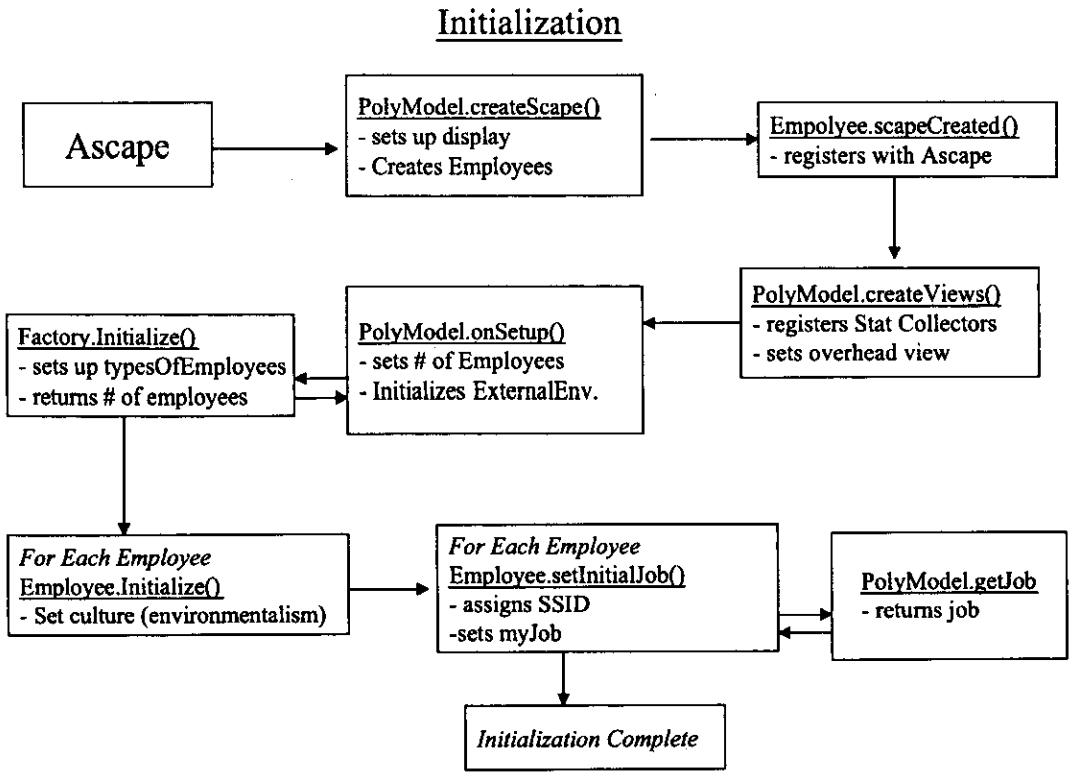

Fig. 3. PolyModel initialization logic.

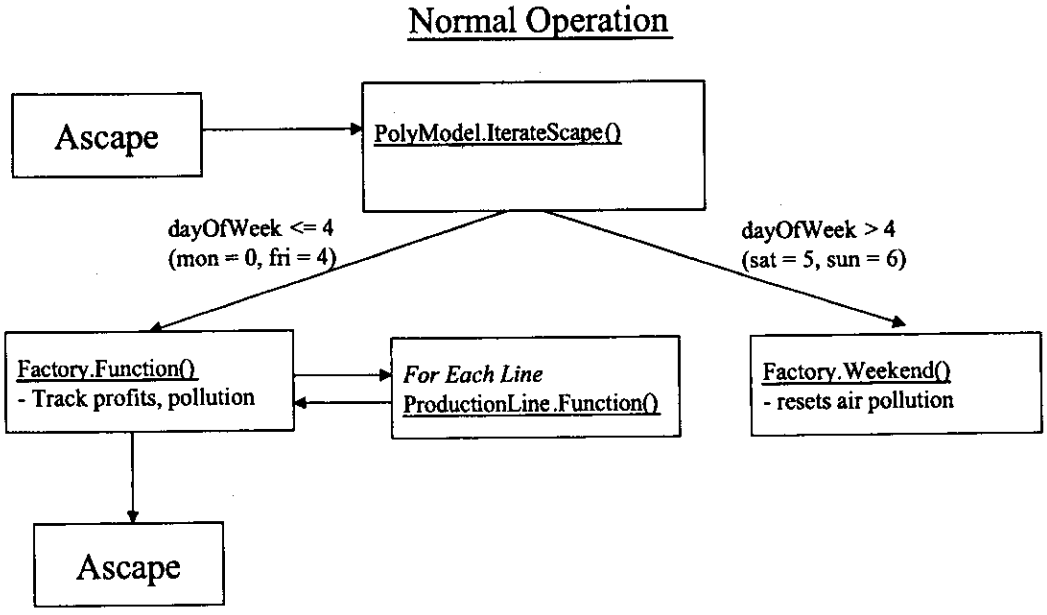

Fig. 4. PolyModel normal operation logic.

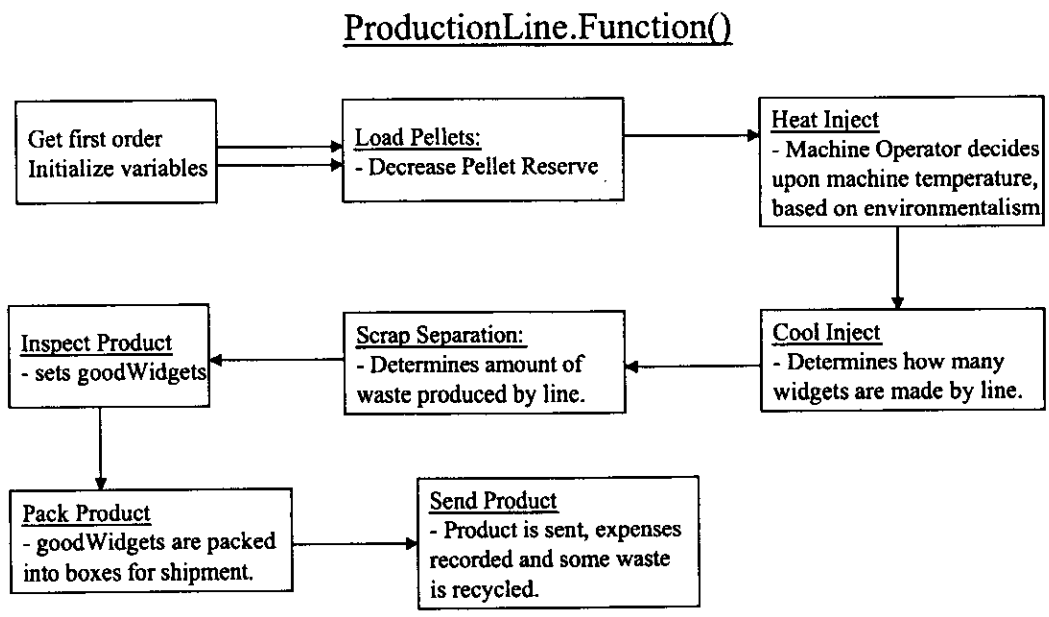

Fig. 5. PolyModel production technology logic. It mirrors that described in Figure 1.

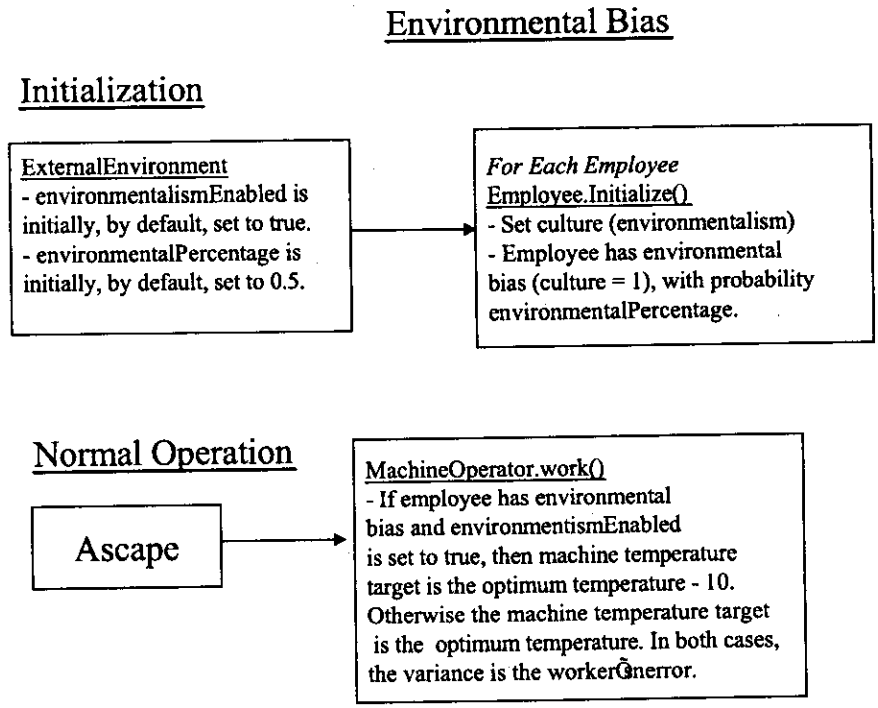

Fig. 6. How an environmentalist bias was implemented in PolyModel.

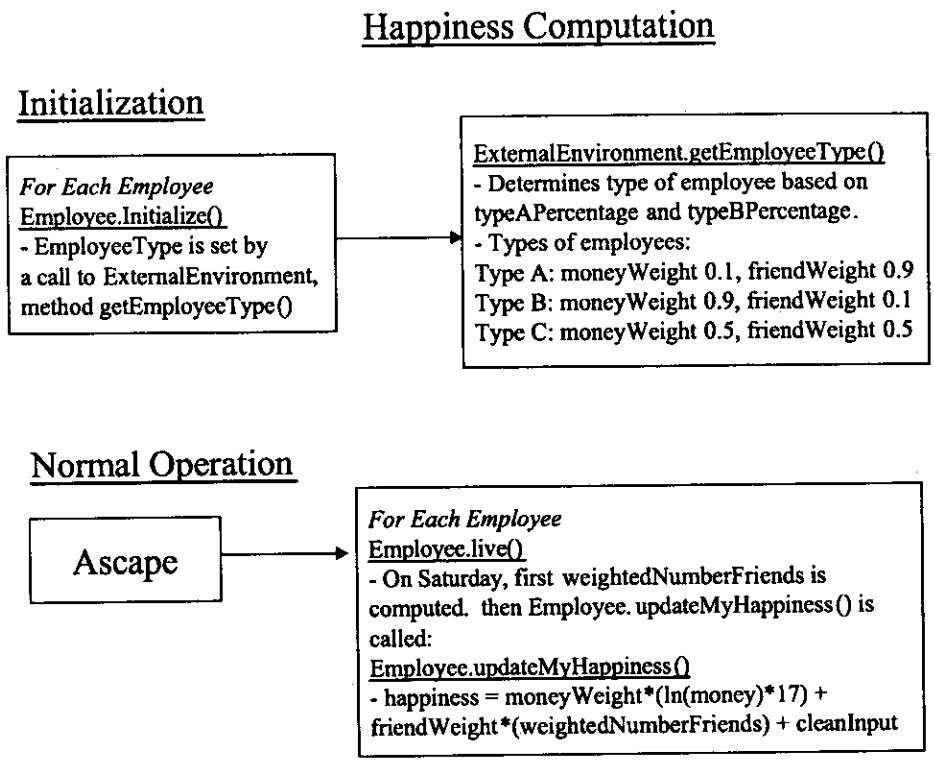

Fig. 7. Employee utility functions implemented in PolyModel.

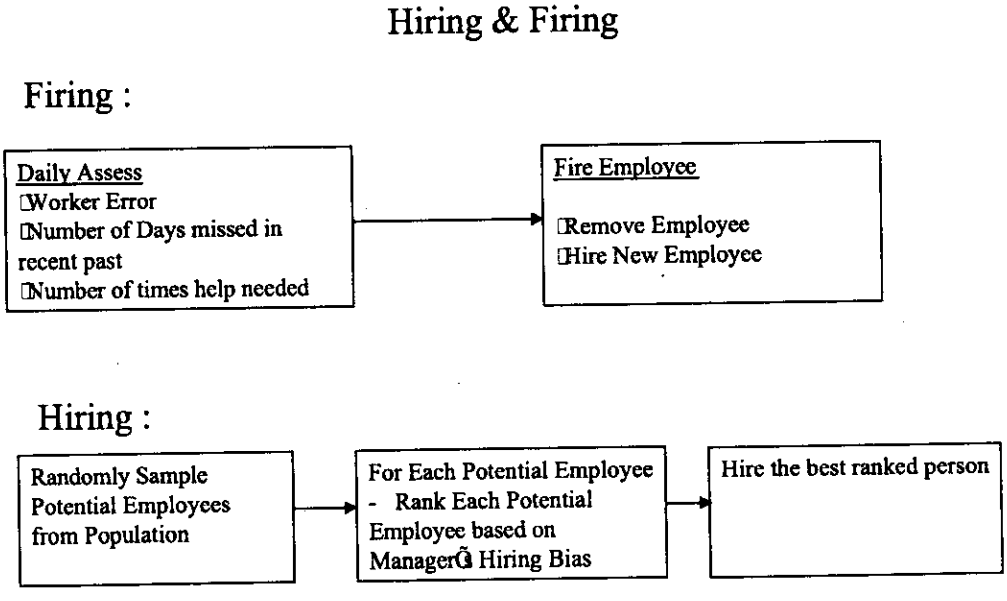

Fig. 8. PolyModel's hiring and firing logic, executed by the plant manager.

Illustrative results

This paper briefly discusses one set of illustrative results. The project continues as of this writing, so that the model, underlying theories, and empirical evidence are evolving. The goal is to make the model robust enough to serve as a management-training simulator for the plastic injection molding industry.

Figures 9 and 10 compare profitability and environmental performance of the firm over a multi-year period under two representations of bounded rationality among employees. Under standard *homo economicus* assumptions, the firm is much more profitable and less polluting than when the model is populated with more realistic employees who commit worker errors.

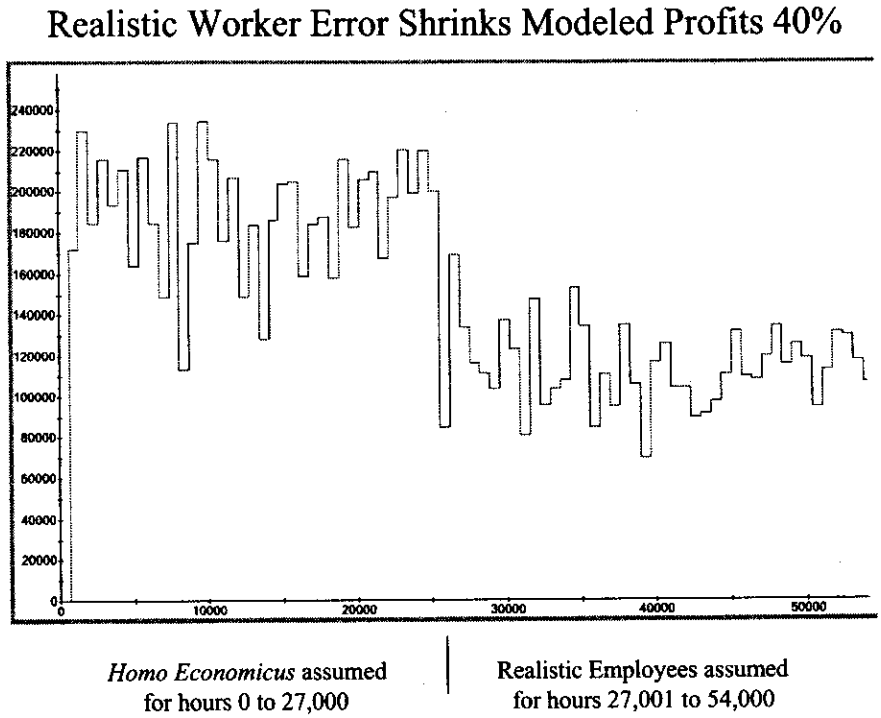

Fig. 9. Monthly profits under two sets of assumptions regarding worker error.

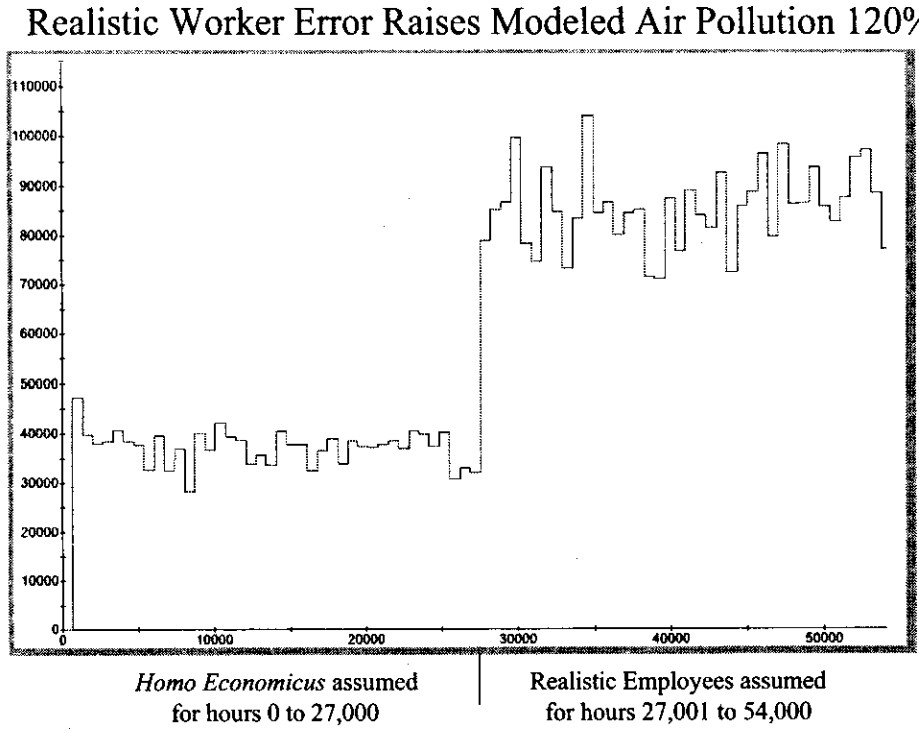

Fig. 10. Monthly air pollution under two sets of assumptions regarding worker error.

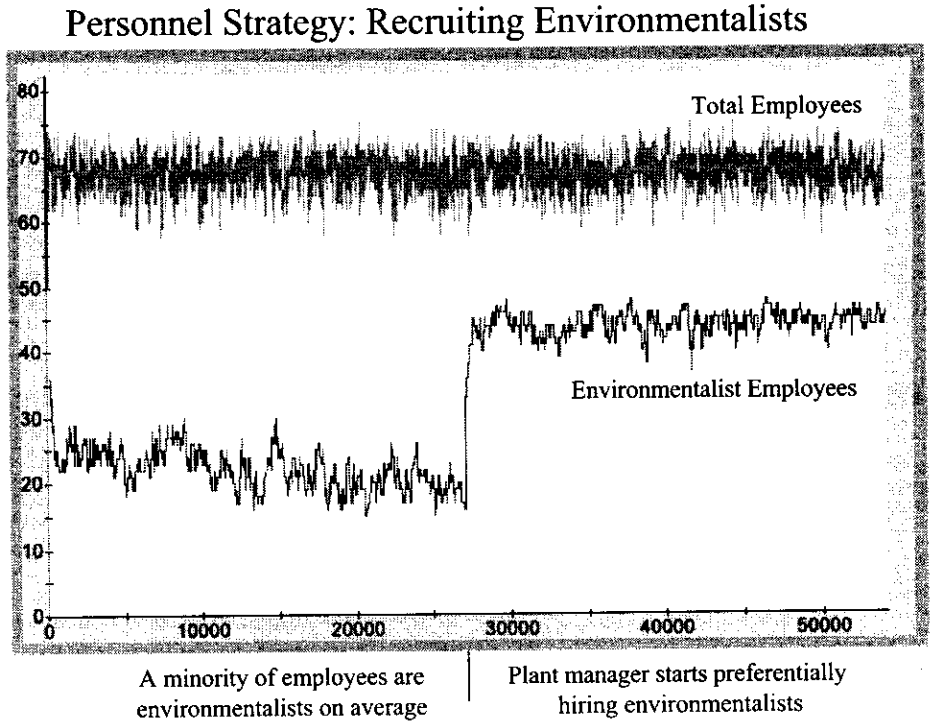

Fig. 11. Employees and employee composition under two hiring scenarios.

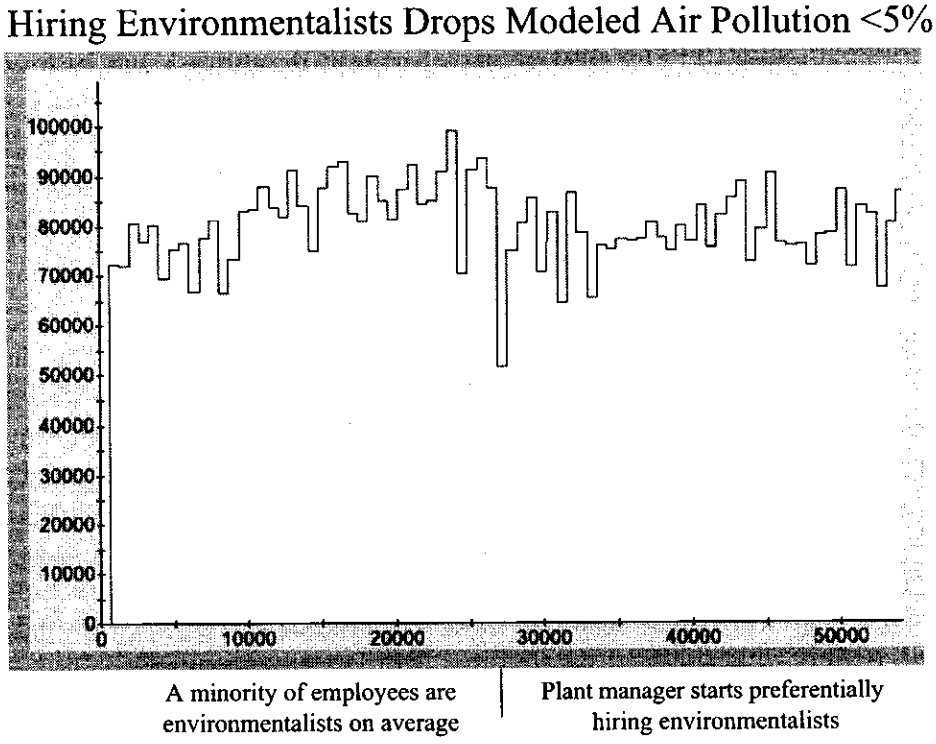

Fig. 12. Monthly air pollution under two hiring scenarios.

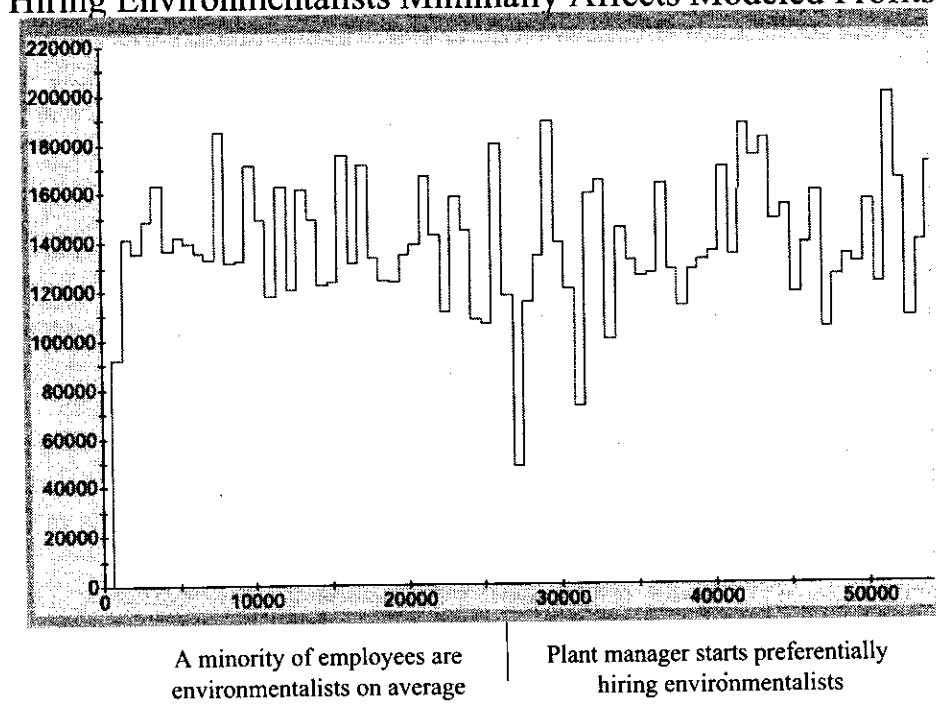

Fig. 13. Monthly profits under two hiring scenarios.

Figures 11, 12, and 13 show what happens when the plant manager preferentially hires environmentalists. The environmental benefit is minimal, but luckily so are the impacts on profits. A quality management strategy (suggested by Figures 9 and 10) seems more likely than an environmentalist hiring bias to improve corporate environmental performance, while simultaneously improving financial performance.

Theory building

Regarding the motivating question for this project—can multi-agent simulation advance organizational behavior research by better linking evidence with theorizing?—the results are promising. The set of simulations shown in Figures 9 through 13 illustrates how both frictionless neoclassical theories (that miss worker error) and human relations/social network theories (that miss technological factors) are incomplete. The former will never help managers discover the benefits of total quality management strategies. The latter will never help managers discover the benefits of technological improvements. The multi-agent simulation illuminates both, plus other insights.

In addition to what has been shown in the figures, the modeling and case study evidence support two more insights to date. First, informal networks are very important for hiring new employees and for helping employees to decide to take job actions like strikes and sick day protests. Second, formal structures are hugely important for explaining almost everything else. In this industry there also appears to be a substantial amount of technological determinism. In other words, the type and economics of the technology explain much of the firm's overall behavior.

Lessons learned

There are two major lessons learned for researchers interested in using multi-agent simulation models in a grounded theory-building context. First, this project shows that highly diverse skill sets are needed. In fact, it is unlikely that a single individual will have the requisite range of skills, necessitating recruitment of a multidisciplinary team consisting of an interviewer, case study developer, and Java programmer. Second, iterative modeling and interviewing is crucial because new questions arise, and alternative theories need to be explored and elaborated.

A benefit of developing multi-agent simulations in this inductive, evidence-based way is that they appear to inform action more directly than might deductive, theory-based models. Organizational behavior becomes a humbler but perhaps more valuable type of social science—less general but more applicable.

Acknowledgements

The authors gratefully acknowledge financial support from the U.S. Environmental Protection Agency's Science To Achieve Results grant program in Corporate Environmental Behavior. They also acknowledge Robert Axtell's collegiality and profusely thank the plastics manufacturers who allowed case study visits.

References

Project website with case study and model details and is at http://policy.rutgers.edu/andrews/projects/abm.

Andrews, C.J. (2002) Humble Analysis, Praeger, Westport, CT.

Babbie, E. (2003) The Practice of Social Research, 10th ed., Wadsworth, Belmont, CA.

Eisenhardt, K.M. (1989) "Building theories from case study research," Academy of Management Review 14(4): 532-550.

Glaser, B.G. (1992) Basics of grounded theory analysis: Emergence vs. forcing, Sociology Press, Mill Valley, CA.

Glaser, B.G., and A.L. Strauss (1967) The Discovery of Grounded Theory: Strategies for Qualitative Research, Aldine, Chicago.

Lofland, J., and L.H. Lofland (1995) Analyzing Social Settings: A Guide to Qualitative Observation and Analysis, 3rd ed., Wadsworth, Belmont, CA.

Popper, K.R. (1968) The Logic of Scientific Discovery, 3rd ed. rev., Hutchinson, London.

Strauss, A., and J. Corbin (1998) Basics of Qualitative Research: Techniques and Procedures for developing Grounded Theory, 2nd ed., Sage Publications, Thousand Oaks, CA.

Tukey, J.W. (1970) Exploratory Data Analysis, Princeton University Press, Princeton, NJ.

Wallace, W. (1971) The Logic of Science in Sociology, Aldine-Atherton, Chicago.

Yin, R.K. (2003) Case Study Research: Design and Methods, Sage Publications, Thousand Oaks, CA, pp. 44-51.