



FIGURE 2
SugarScape Model Running Using RePast

when faced with the inherent uncertainty in addressing long-term, vital questions such as global sustainability.

Agent-Based Modeling Toolkits NetLogo, RePast, and Swarm

Reviewed by **Duncan A. Robertson**, University of Warwick, UK.

Management educators are always seeking new and exciting ways of teaching key concepts to their students. Agent-based models are one way of communicating management ideas using a method that is inherently visual—one that can capture the attention of students and executives alike.

Agent-based models are gradually making their way into management research. Although this review does not consider the use of agent-based models in management research and does not give an in-depth insight into agent-based modeling concepts (readers may wish to consult Robertson, forthcoming, for these purposes), what is intended is to expose readers to a small selection of agent-based modeling packages to see whether and how they can incorporate them into their teaching.

"Agents" can include firms, people within organizations, or entire industries: Agent-based modeling allows the user to define the interactions be-

tween these agents and then use these to generate models. Agent-based models define the interactions between these agents, whether they be for example interactions between firms or the interactions between people within a firm. What makes this technique exciting for a taught audience is that the models are inherently visual, as can be seen from the screenshots (Figs. 1, 2). Students can see the dynamics of the interaction between agents and the subsequent effect on other agents. This generally sparks a discussion between students, and can therefore, be used as a discussion tool in order to initiate debate, debate that may well be augmented with the use of other teaching methods such as case studies. While the use of agent-based models alone is often not sufficient to explain all the intricacies of a chosen management concept, they can supplement traditional techniques. Agent-based models are particularly suitable for modeling complex systems, where many agents interact; there is therefore scope for using these toolkits to illustrate some of the more recent concepts within management, particularly those where the micro level behavior of individuals affects the global, macro properties of a system.

As with any new method, knowing where to start can be a significant obstacle in introducing the technique into a course. I review three agent-based modeling toolkits in order to point readers to

an appropriate place to start investigating agent-based models, to decide whether there is a place for them in their courses: *NetLogo*, *RePast*, and *Swarm*.

The first is *NetLogo*, a system that is very easy to install and to operate: Users can explore models without any technical knowledge; an extensive "models library" exists so that users can see the types of models that have been made using the toolkit. These are generally well documented, the documentation being easily accessible through the "information" tab within the program. Parameters of the model are easily changed using graphical "sliders." For those who want to change the details in a model, clicking on the "procedures" tab brings up the entire model code, which can easily be changed in order to extend the sample models. *NetLogo* provides a very accessible introduction to agent-based modeling. This is a very useful first step after which users can decide whether the technique is one that warrants further investigation (Figure 1).

For those more adventurous readers, or those with some experience in programming, *RePast* is the obvious next step. It provides an extremely

wide set of "libraries" for developing models. As with *NetLogo*, several sample models are available that are easily downloaded and run. However, to extend these models requires a reasonable effort, for example in installing a facility such as *JBuilder* for editing *Java* programs. One of the key features of *RePast* is that it was set up and is maintained by a group of social scientists, which means that social networks, genetic algorithms, systems dynamics, and geographical information systems (GIS) are all supported. However, the time to develop a new model will be significant unless you have relatively good *Java* programming skills. But there is a good community of model builders, all keen to support new members of the *RePast* community (Figure 2).

For completeness, I also mention *Swarm*, as this may often be considered as a viable option by people new to agent-based modeling. *Swarm* is now looking relatively geriatric at the early age of about 10 years. Although still very usable by the expert, it is not designed specifically for social science applications, and is not well supported. It is also extremely tricky to install or run successfully.

TABLE 1
Selected Agent-Based Modeling Packages

	<i>NetLogo</i>	<i>RePast</i>	<i>Swarm</i>
Developed by	Northwestern University (Center for Connected Learning and Computer- Based Modeling)	Repast Organization for Architecture and Development (originally University of Chicago Social Science Research Computing)	Swarm Development Group (originally Santa Fe Institute)
Advantages	Very easy to set up and run models.	Many users, good support from the <i>RePast</i> community	The precursor to <i>RePast</i> and to a lesser extent <i>NetLogo</i>
Example models	Many	Many	Only a few are readily available.
Disadvantages	Very complicated models are outside the capability of <i>NetLogo</i> , mainly for abstract models.	Need to be able to understand a programming language (e.g., <i>Java</i>)	Extremely difficult to install and run on a Windows computer.
Time required to start building models for programming novice	A few hours	A few days	A few weeks
Limitations	Models created cannot be easily extended.	Very versatile system. Models can be extended very easily subject to at least some knowledge of e.g., <i>Java</i> .	Difficulty in installation, not well supported, especially by the social science community
Support from academic community	High	High—especially from social sciences academic community	Relatively low
Active maintenance of software	High	High	Low
Additional features	3D visualization of models. Models can be embedded in web pages.	GIS implementation	Complicated to install

So which toolkit to use? In summary, *NetLogo* (for beginners wanting to make models work), or *RePast* (for people wanting to extend models or for those with good programming skills). *Swarm* is the grandfather of them all and is not recommended, at least initially for the nonexpert.

All the toolkits ultimately provide a similar end result: the ability to model, to manipulate, and inspect agents. *NetLogo* has a simple interface, models can be set up and run with only the push of one or two buttons; to produce the model such as the one illustrated takes just 50 lines of simple code. Compare this to the simulation in Figure 2, using *RePast*, which requires 950 lines of code, much of it quite complicated. However, this reflects the potential complexity of each of these toolkits: *NetLogo* is good for setting up simple simulations very quickly, while *RePast* allows simulations, perhaps trialed using *NetLogo*, to be expanded and made more sophisticated (Table 1).

As more educators develop their own models,

management-specific models will become available to our community. For the moment, we have to start with models from other disciplines (such as social science or natural science) that can be adapted to shed light on management problems. This is a call to arms for educators to get their hands dirty—to download *NetLogo* to see what models exist, to use tools such as *NetLogo* to develop their own models, then (if still enthusiastic) to develop their own models using *RePast*. And finally, to report their findings back to *AMLE* so that we may share in their rich experiences.

REFERENCES

NetLogo, <http://ccl.northwestern.edu/netlogo/>

Repast, <http://repast.sourceforge.net/>

Robertson, D. A. In press. Agent-based models in management research. *Organizational Research Methods*.

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