Modelling Critical Infrastructure Interdependencies Using Software Agents and the JADE Framework

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Introduction

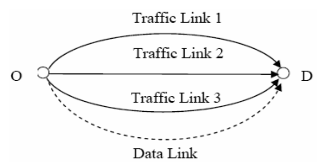
Infrastructures critical to the function of society are heavily interdependent and influence the operation of each other. The complexity of the infrastructures and their interdependencies make systems of infrastructures very difficult to model and simulate. Using software agents is a promising technique for simulating such systems due, in part, to their ability to model the behaviour of the actors as autonomous entities with individual goals rather than a centrally-controlled system. This tends to be closer to the actual operation of such systems.

Objective

This study was done to expand on work done by Zhang *et al.* to model the interdependencies between two infrastructures, the roadway system and the telecommunications network, and to judge the effectiveness of software agents as a means of building such models.

Experiment

The situation modelled is that of a simple scenario where an agent is presented with a daily choice of telecommuting or driving to work. If the agent chooses to drive to work it must select one of three routes.



•All agent decisions are based on data from the previous day

•The probability of driving to work is based on the relative costs of telecommuting (fixed) and yesterday's trip cost.

$$\Pi_A = \frac{e^{-\rho c^A}}{e^{-\rho c^A} + e^{-\rho c^D}}$$

•Each roadway route has a cost that is based on the number of agents using the route (the route flow) and some route specific parameters.

$$c_a(f_a) = A_a + B_a\left(\frac{f_a(t)}{K_a}\right)^4$$

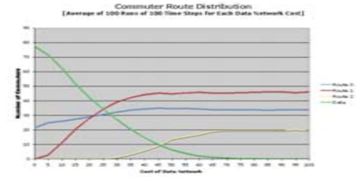
•The probability of an agent changing routes is dependent on the difference in cost between the agent's previous route and the cheapest route.

$$P = e^{\frac{-\theta}{c_{current} - c_{best}}}$$

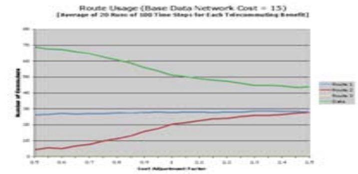
Results

Without telecommuting, the average flow on the three roadways converged; however, individual runs converged to one of a set of values and not the average value.

When telecommuting was added, as expected, the flows converged at different levels dependent on the cost of telecommuting.



When the cost of telecommuting is exponentially increased (or decreased) based on the number of consecutive days the agent has chosen to telecommute, the traffic flow levels reflected the increased (or decreased) average cost of telecommuting.



Conclusions

• Agent-based systems provide a means of simulating complex interactions (such as the stochastic nature of the commuter decisions and non-trivial mathematical relationships in this model) that are impossible, or at least computationally very expensive, using traditional flow-dynamics techniques.
• Agent-based design provides a very easy means of changing system models based on changes in agent behaviour.
• Agent-based simulations can expose hidden aspects of system models (such as the multiple "steady states" in this model).

The combination of easily modified system models based on agent behaviours and the potential to highlight information about models that may be unavailable or overlooked by traditional techniques proves the value of agent-based modelling of complex systems such as infrastructures and their interdependencies.

What are Critical Infrastructures?

A traditional definition of *infrastructure* is "the basic facilities, services, and installations needed for the functioning of a community or society" (dictionary.com). Governments have recently come to realize the extent to which society relies on certain infrastructures (dubbed *critical infrastructures*) and have developed policies devoted to their protection. Canada lists nine infrastructures considered to be critical to Canadian society:

- energy and utilities
- transportation
- manufacturing
- government
- communications and information technology
- finance
- food
- water
- health care
- safety

What Are Software Agents?

Wooldridge defines a software agent as "a computer system that is situated in an environment and that is capable of autonomous action in this environment in order to meet its design objectives." One can think of agents as an abstraction that allows software to be designed based on desired behaviours rather than on methods and and attributes as is done in object-oriented design. While there is no standardized definition for agents, they typically have the following properties:

•Persistence - their code runs continuously; they are not allotted run time by a controlling program.
•Autonomy - agents choose their own actions: they are not told what to do; they choose the best way to meet their goals.
•Social Ability - agents can communicate with other agents (to cooperate, negotiate, etc.).
•Reactivity - agents are able to sense their environment and react to changes.

What is JADE?

JADE (Java Agent DEvelopment framework) is a framework in which to develop agent-based applications compliant with FIPA specifications for interoperable multi-agent systems. JADE implements an agent platform and a development framework. It deals with all the aspects of agent creation that are not specific to the agent internals and that are independent of the applications, such as message transport, encoding and parsing, or agent life-cycle. [http://jade.tilab.com/]

Referenced Works

M.J. Wooldridge, *An Introduction to Multiagent Systems,* West Sussex, England: John Wiley & Sons Ltd, 2002,

P. Zhang, S. Peeta and T. Friesz, "Dynamic Game Theoretic Model of Multi-Layer Infrastructure Networks," *Networks and Spatial Economics,* vol. 5, pp. 147-178, 2005.