Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

INTEGRATING AGENT BASED MODELING INTO A DISCRETE EVENT SIMULATION

Benjamin Dubiel
Omer Tsimhoni

Department of Industrial and Operations Engineering
1205 Beal Avenue
University of Michigan
Ann Arbor, MI 48109, U.S.A.

ABSTRACT

Movement of entities in discrete event simulation typically requires predefined paths with decision points that dictate entity movement. Human-like travel is difficult to model correctly with these constraints because that is not how people move and large individual differences exist in capabilities and strategies. Agent based modeling is considered a better way to simulate the real-time interaction of people with their environment. In this paper we propose to integrate agent based modeling with discrete event simulation to simulate the movement of people in a discrete event system. An agent based module was constructed within the AutoMod simulation package, and a test case was modeled in which people (agents) at a theme-park interact with objects and people in their environment to get directions and then walk or take a tram to their final destination. We explain the details of model implementation and describe the verification and initial validation of the model.

1 INTRODUCTION

The benefits of Discrete Event Simulation (DES) are well documented throughout industry, military and academia (E.g., Banks et al. 2003; Banks, Carson, Nelson, and Nicol, 2001; Law and Kelton 2000). There are certain situations, however, that are very difficult to simulate using DES. Any model that requires free movement of entities or a very detailed movement pattern is not easily simulated with DES. As an example, service systems through which humans flow in unpredictable paths, while quite common, are difficult to model in DES. Very strict assumptions about the human's choices have to be made by the modeler in order to fit their behavior into the format of DES modeling. Furthermore, the real-time decisions of individual entities would be very difficult to model using DES.

The primary limitation of DES involves the generality of movement and function of entities in the simulation world. In all commercial DES packages, a path must be drawn from point A to point B in order for an entity to move between those two points. This requirement makes the modeling of human movement with DES unrealistic in situations where paths are not predetermined (e.g., modeling congestion in a gift shop or the exit of patrons leaving a sporting event). It is difficult to map every path the entity could take between two points, and even more difficult to assign probabilities to each of those paths for the navigating between the two points. A second limitation of DES involves the ability of an entity to make decisions at very small time increments. To do this in a DES, an analyst would need to place a large amount of decision points extremely close to one another along the path of travel, while also programming the required decision logic to be processed at each point. This process is not only laborious, but the results would be difficult to verify and validate. A third limitation of DES that affects the modeling of human-like travel is that processing is done at user-defined decision points and is not autonomous to the flowing entities. Because any processing or routing decisions must be made by the DES servers, intelligent entities cannot be modeled directly. This, in turn, limits the entities' human-like function and could have an effect on the interaction between the entity and all other objects in the simulation world. It should be noted that all of these limitations can be overcome using DES functions and clever programming, but that does not negate the fact that DES is not well-suited to the modeling of human movement and decision patterns.

Agent Based Simulation (ABS) offers a more straight forward and accurate solution to these issues. ABS attempts to simulate intelligent, autonomous entities (agents) as they interact to attain some goal in their environment. This simulation approach has been used to model many different situations such as social evolution, segregation, disease propagation, and advertisement effectiveness. ABS has become a highly researched topic in the simulation industry over the past decade. Since 2000, several Conferences have formed (MABS, ABS, and AAMAS) and many well established conferences (WSC, SimSol, and the SCS conference series) have opened tracks focusing strictly on this powerful simulation approach.

In “Growing Artificial Societies”, Epstein and Axtell (1996) state that an ABS consists of three primary elements: single or multiple autonomous agents, an environment or space, and rules that govern the movement and interactions of the agents. With this definition, developing an agent based module to simulate human movement is possible as long as the agents are kept autonomous and the correct rules are implemented to control their actions.

There are several software packages that can be used to build agent based models. Among these are: AnyLogic, (X J Technologies 2005), the EXODUS packages, (FSEG 2003), RePast (RAST 2005), and Swarm (Introduction to Swarm 2005). Each of these packages is very specialized and is designed to produce a specific model type such as models with a large number of individuals (AnyLogic or Swarm) or models that observe the behavior of individuals in emergency situations (Exodus packages). Some of these agent based packages can model simple human-like travel, but none of them can integrate easily with common DES packages.

In this paper, we argue that ABS can be integrated with DES to model humans traveling freely through a DES system. Adding the functionality of human-like movement to a commercial DES package is extremely relevant when considering simulation in the service industry and particularly the theme park industry. The ability to model scenarios including free moving, pseudo-intelligent individuals is a very desirable tool, as this would allow for the modeling of flow and design scenarios while utilizing existing DES models of service and transportation systems around theme parks.

We explore the integration of ABS and DES through a test case which represents a real-world problem from the theme park industry. A customer with limited knowledge of the surrounding environment searches and walks to an information source to obtain the location of a goal object and then either travels on a discrete movement system (tram) or walks to the goal object. The model can be used to answer questions about location and quantity of maps, signs, and informed employees in order to minimize travel time of customers and maximize flow around parks. This model could also predict arrival patterns to the discrete components in the system (tram or queues) for multiple different configurations of information sources. Overall this integration would benefit many different scenarios where free movement of entities was required.

2 SOFTWARE IMPLEMENTATION

The student version of the AutoMod simulation package was chosen for the building and experimentation portions of this project. This decision was made due to the first author’s detailed knowledge of the package, along with the fully defined 3-D coordinate modeling space available in AutoMod. With this feature, it is possible to build the physical portion of an agent based model that will allow agents to move freely throughout the environment. As a proof of concept, the cognitive and interaction modeling was based on a very simplified model of human perception, decision making, and movement. More complex computational algorithms representing human behavior can be added at a later point.

For simplicity purposes, the Agent Based Module (ABM) was designed to be implemented from within the DES environment to allow for the well defined features of AutoMod to interact seamlessly with the agents. It is certainly possible, however, to implement ABM as a separate module that interacts with DES externally. This option was not explored because the external ABS packages available did not fit the needs of the authors for this project.

A schematic diagram of the overall system design can be found in Figure 1. The ABM module contains four types of objects:

- **Dynamic Seeking Agents** - Models an individual attempting to locate an object in the environment
- **Dynamic Informative Agents** - Models individuals who are familiar with the simulated world
- **Stationary Informative Objects** - Models maps or signs in the environment
- **Stationary Non-Informative Objects** - Models obstructions to agents path (e.g. Trees)

These objects can locate and identify each other by storing their visible characteristics in a dynamic model of the physical environment (physical information arrays) that is accessible by all objects in the ABM. Any characteristics that are not visible, such as knowledge of the surrounding area, are stored in the object’s internal information space. The internal information space of the Dynamic Informative Agents and Stationary Informative Objects can be accessed by the Dynamic Seeking Agent through an interaction (as described in detail in section 5). Seeking Agents can move in and out of the ABM to utilize DES functions that are integrated into the model. It is important to note that both types of agents in the module have the same overall design, except that the Informative Agent never interacts with DES functions.

The decision to include two forms of information sources (Informative Agent and Informative Object) was made in order to test two major functions of ABS.

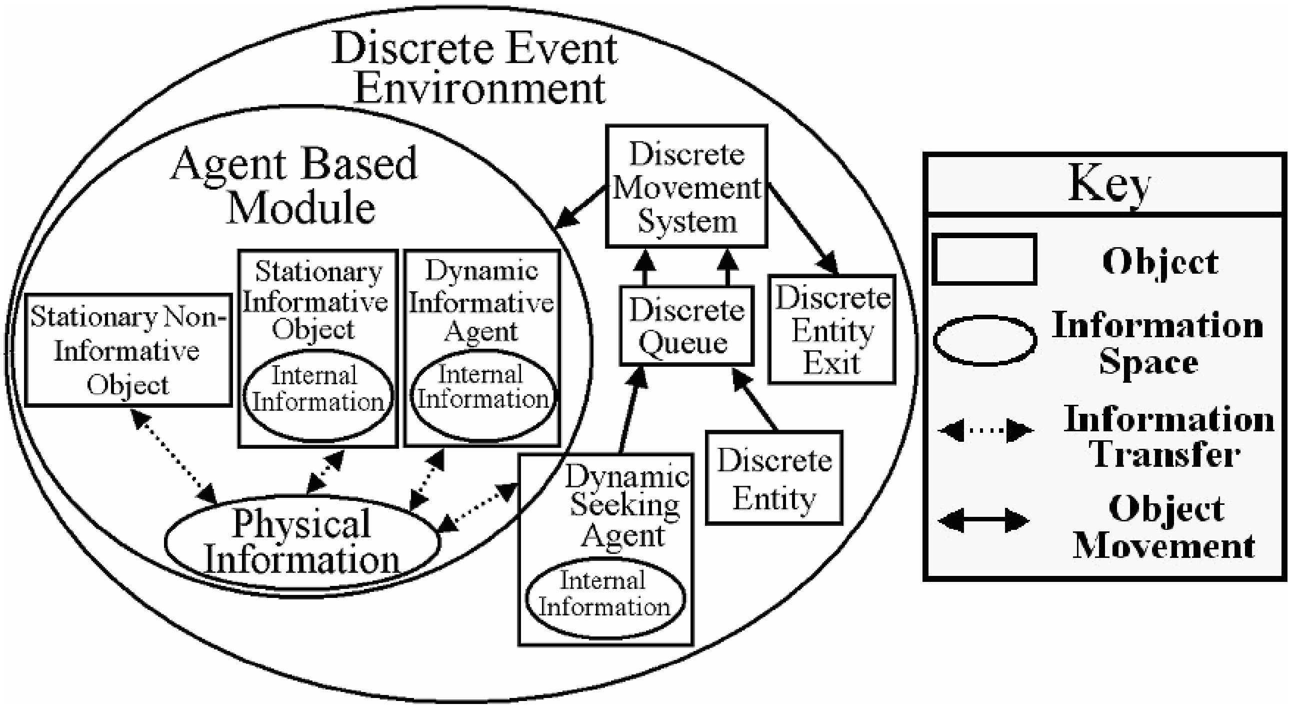

Figure 1: Integration of an Agent Based Module with the Discrete Event Environment

As Huberman and Glance (1993) describe in their paper on evolutionary systems, if the initial action of an agent is the same throughout all experiments, it becomes likely one agent will have an advantage over another based on the starting condition.

By including two different types of information sources and randomizing the agent's initial angle (field of vision), the validation and verification of the decision logic becomes easier and a fair starting condition is obtained.

Using these two information sources also gave the ability to experiment with the different forms of interaction between two agents that are possible in an ABS: those that require effort by both entities (strong) and those that require only one object to complete the interaction (weak) (Michel, Gouaïch and Ferber, 2003).

3 TEST CASE

The test case for this project is based on a single Seeking Agent interacting with information sources in order to find a goal object located in the simulation world. This case is meant to model an individual attempting to obtain directions and then using those directions to navigate to a desired location (goal object).

Figure 2 demonstrates the major features of the test case. The Seeking Agent enters the model at a random point with all the basic decision logic required to find an information source and interact with it to obtain the location of the goal object. Once the Seeking Agent has obtained the location of the object from an information source, it navigates through the simulation world to obtain the object. There are two transportation methods shown that the Seeking Agent can use to get to the goal object. If the Seeking Agent uses a Stationary Informative Object (map), they will walk to the location of the goal object, which will take approximately 10 minutes to perform (depending on the agent's walking speed).

If the Seeking Agent obtains the directions from an Informative Agent (person), they will utilize a tram (a discrete movement system) that is available. The tram has an inter arrival time of 5 minutes and takes 1.5 minutes to transport the agent. There is also the possibility that the Seeking Agent will misinterpret the information given and get lost. In this case, the Seeking Agent will travel to the perceived location of the object, and if nothing is found, will return to the original location of interaction. This test case was developed in order to build and test the module during the initial stages of development.

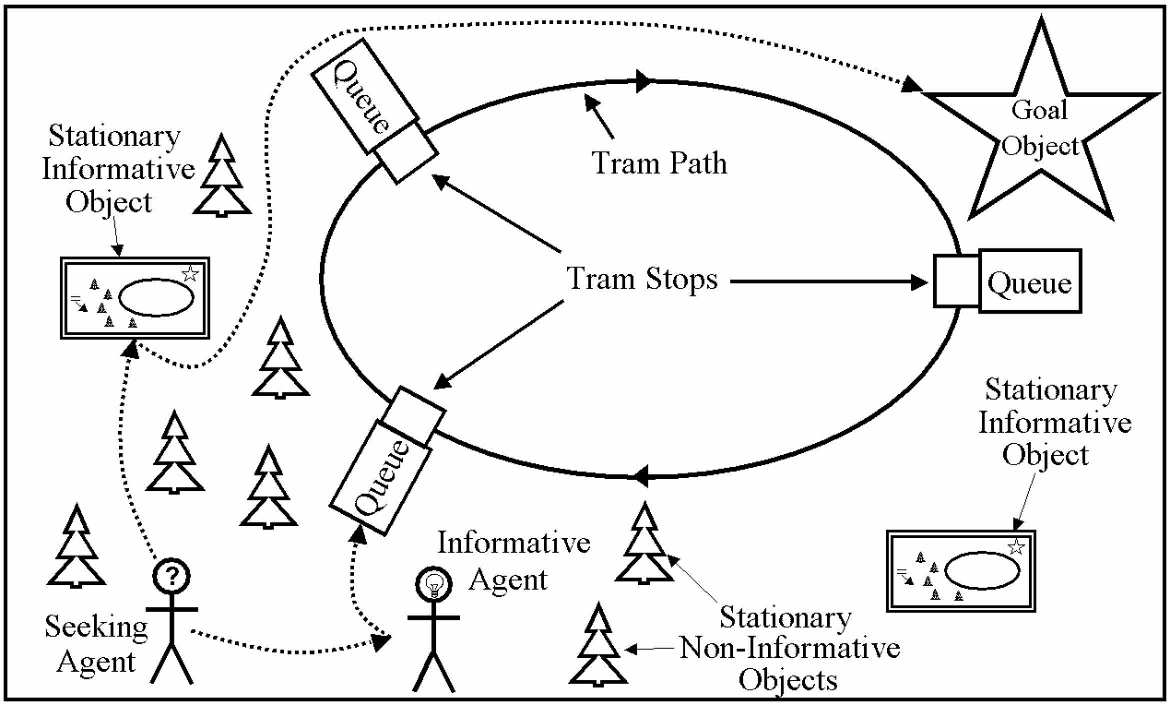

Figure 2: Physical Layout of the Environment and Some Possible Test Case Scenarios

4 ENVIRONMENT MODELING

As seen in Figure 1, the environment is the DES model space in which all actions and interactions take place. The information available to each agents from the environment can be broken down into two main segments: the visible characteristics available to all agents in the model (physical), and the characteristics that are known only by the individual agent (internal) that can be obtained through interaction with other agents or objects. The environment modeling was implemented using the grid method (Epstein and Axtell 1996). This method uses (X,Y) coordinates of each object as the basis for the physical interaction in the model. Multiple global array were used to hold all physical and internal attributes of the agents and objects in the simulation world. These arrays included (X,Y) coordinates, current angle of rotation (head and body), object type, object shape, current state, and knowledge of surroundings. Although these arrays are global, great care was taken to limit the information available to all agents in the model in order to maintain the integrity of the physical versus internal information.

Object type, shape, size and state are used to determine the type of action and interaction that will occur as the simulation progresses. As the work for this module continues, a larger variety of objects will be integrated in order to further the functionality of the module.

The interaction of the agent based entities with the DES features was implemented using a trigger location and variable combination. If the Seeking Agent desired to ride the tram presented in the test case, they were required to travel to the trigger location and a Boolean value was set to indicate to the ABM that the Seeking Agent should be transferred to the discrete movement system. The Seeking Agent was then moved out of the ABM and placed into the discrete queue to wait for the arrival of the tram.

5 MODELING HUMAN TRAVEL

The degree of detail with which intelligent agents in the model represent real humans is likely to vary with the specific requirements of each model. For the purposes of this test case, it is desired that information seeking agents (visitors at the park) will have several basic abilities. They should be able to perceive their environment (mainly visually), have navigation goals (e.g., I want to get to Space Mountain), know when they need to ask for directions (meta knowledge) or use maps for directions, avoid obstacles (guidance) as they move around, interact with other people, and utilize the knowledge obtained from the interactions to navigate to a goal object.

To achieve these goals, all agents were programmed to have visual and auditory perception, cognitive abilities such as searching and decision making, and the ability to control their movement at a gross level.

5.1 Perception

The vision of the agents is modeled using physical information arrays along with trigonometric functions to determine the agent's field of vision. Once visible objects are determined, the peripheral and foveal vision memory of the Seeking Agent is populated with physical information of each visible object. The peripheral vision extends 180 degrees horizontally around the agent's direct line of sight, while the foveal vision spans two degrees. If an object is in the agent's peripheral vision, the Seeking Agent can perceive the general characteristics of the object (detect its existence, size, and movement). In order to determine if the object is a target or distracter, the Seeking Agent must look at the target (using foveal vision).

The vision memory processing is performed at regular intervals (once every 50 milliseconds) as long as the Seeking Agent is not moving their eyes. The visual processing continues while the Seeking Agent is in transit. This parallel processing allows agents to make decisions such as avoiding obstacles or changing route while moving .

As a further addition to the vision function of agents, all objects in the model have a defined salience (prominence) level which represents the features of an object that make it stand out against its background. Some of these features include contrast, luminance, color, size and shape (Wickens, Gordon and Liu, 1998). In the current implementation, all of these factors are simplified and summarized as a single salience level defined from 1 to 10. This attribute is a main factor in the searching method of the Seeking Agent as described later in this section. Once an agent's vision memory has been updated with the characteristics of the visible objects, it runs the decision logic.

A separate factor to further model the perception capabilities is the agent's range of vision. This attribute describes the maximum distance where the Seeking Agent can differentiate between objects. In all experiments, this factor is set to be 400 feet, but can be changed to simulate visibility conditions and differences in individual characteristics.

5.2 Decision

The decision logic is implemented based on the current decision state of the agent. A simplified list of the decision states and the decision progression is shown in Table 1.

A Seeking Agent proceeds through these states, in the described order, until it has reached the goal object. The starting state of the Seeking Agent is determined by the confidence the agent has in their personal knowledge of the location of the goal object. Each Seeking Agent enters the model with this confidence factor assigned to them randomly. This factor along with the perceived location of the goal object determine the agent's flow through the decision logic. If the agent's confidence is greater than a high threshold (set at 85%), they do not ask for directions and proceed directly to step 11 using their perceived location of the goal object. A Seeking Agent has a 50% probability of knowing the correct location of the goal object upon entering the model. The agent's knowledge of the location was not made to correlate with their confidence in order to determine the modules function when an Seeking Agent becomes lost.

Table 1: Description of the Agent Decision States

Step	Description	Next Step
1	Searching for IS	2
2	Decide on Action	1, 5 or 6
3	If nothing found => rotate body	1 or 4
4	If nothing found => travel	1
5	Found Informative Object => travel	6
6	Found Informative Agent => travel	9
7	At Informative Object => interact	11
8	At Informative Agent => interact	11
9	Emit verbal signal	8
10	Respond to verbal signal	8
11	Go to goal object	End/Next Object

If the Seeking Agent does not have the required amount of confidence to proceed to the goal object, it flows through the decision logic as shown above. Once the Seeking Agent has determined the location of the goal object with an adequate confidence by interacting with information sources, it walks or travels to the location.

A sociability parameter accounts for the agent's tendency to approach a person rather than look for a map. This parameter is given a value of zero if that Seeking Agent will not approach an Informative Agent until it is their last option and a value of one if the Seeking Agent prefers human interaction.

5.2.1 Search

The search functions are performed to locate information sources or targets that are close to the object. The Seeking Agent must do this by distinguishing between targets (an information source or the goal object) and distracters. A distracter is defined as any object in the environment that is of no interest to the agent.

During the search, the Seeking Agent performs two visual processes in parallel, using the foveal and peripheral fields of vision. If a Seeking Agent has a target object in its foveal vision, any information that is received by the peripheral scan is ignored and the Seeking Agent will travel to the target object in sight. If no object is located in the foveal field of vision, the Seeking Agent continues a visual search of its surroundings.

There are two main forms of human visual search; parallel (or feature) and serial (Wickens, Gordon and Liu, 1998; Wolfe 1998). Parallel searches occur when the target object is distinguishable from distracter objects by a single characteristic such as color, size or motion. A serial search is characterized by the systematic search of each item in the field of vision of the individual. The parallel search is much more effective than a serial search. To simulate the parallel search, two factors were taken into account; motion of the object, and salience level. Motion was assumed to be the most prominent factor in the search algorithm, and therefore any moving object in the agents peripheral vision would immediately draw the attention of the agent. When there was no moving object in sight, objects with a salience level that stands out among the other object in the Seeking Agent field of vision (salience difference greater than the threshold) will draw the attention of the agent. The salience threshold for each Seeking Agent in all experiments was set to four (out of 10). If there are no objects that stood out in the agents peripheral vision, a serial search would begin.

When performing a serial search, the Seeking Agent scans the environment by systematically foveating each object in its field of view. Once an object is in the foveal field of vision, its characteristics are processed. If it is not the target, the eyes are moved to a different object. If the target is not found with eye movements, the Seeking Agent turns its head to a new direction and continues a systematic search until a target is found. If a target is still not found, the Seeking Agent starts walking in a randomly selected direction until it encounters an information source or the goal object. This scenario, while not explored during experimentation, could offer some valuable insights as to where to place the information sources to achieve the greatest coverage with the fewest amount of resources.

5.3 Movement

The movement section of the module was separated into two phases: obtaining and chasing. The obtaining phase was implemented when the destination was stationary and the chasing phase was implemented when the destination of the Seeking Agent was moving (a moving Informative Agent).

When obtaining a target that is in view, the Seeking Agent follows the shortest path available to the object. This navigation method is used when traveling to all stationary objects including stationary Informative Agent, Stationary Informative Object and the goal object. The visual perception while moving allows the Seeking Agent to avoid any obstruction in its path. Navigating around obstructions was implemented so as to minimize the agent's distance traveled, as a simulation of real human behavior. To do this, the Seeking Agent begins to alter its path as soon as it recognizes the obstruction. This implementation method ensures the Seeking Agent will travel the shortest possible distance without causing a collision.

When chasing an object, the Seeking Agent perceives the direction of travel of the object (by accessing the physical characteristic array of the object) with a given level of error. This information allows the Seeking Agent to travel on a path of intersection intelligently rather than chasing the objects past position.

The chasing process is terminated when the Agents are in comfortable hearing distance. The Seeking Agent emits a verbal signal ("excuse me") that is perceived by the informative agent when the distance between them is within a given radius (set at 10 feet). The receiving agent then responds by focusing on the emitting agent and engaging in a verbal interaction.

6 INTERACTIONS

The interaction portion of the module was implemented to give the agents a method to obtain detailed and non-visual information from their environment. A discussion of weak vs. strong interactions (Michel, Gouaïch and Ferber, 2003) follows.

6.1 Weak Interactions

A weak interaction typically occurs between an agent and some other (inanimate) object in the environment. This type of interaction requires the attention and consent of only one of the objects involved (the agent) and therefore the inanimate object can interact with multiple agents at one time. Some examples of this type of interaction are a fruit tree as a food source, a map as an information source or a garbage can as a disposal unit.

This interaction type was simply implemented by requiring that the Seeking Agent be at a minimal distance (two feet) from the DIO (map) to obtain the needed information. Once this requirement has been met, the Seeking Agent interprets the needed information (currently implemented as a time delay and a download of information) and proceeds on to the location. In the test case, the agent had a 70% chance of interpreting the information correctly.

6.2 Strong Interactions

A strong interaction is defined to occur between two agents. This type of interaction requires the attention and consent of both objects involved and therefore an agent will first need to gain the attention of the other party before beginning the interaction. Some examples of this type of interaction are any type of society growth or reproduction model, an agent asking for directions, or a call center agent answering a phone.

This interaction type is implemented in the module by utilizing the perception attributes to trigger a change in the decision state of each agent. Once both agents recognize the need for an interaction (verbal signal), their states change as an implementation of the strong interaction logic included in the module. After the interaction is initiated, the Informative Agent tells the Seeking Agent the location of the goal object with a 90% accuracy level. At this time the Seeking Agent terminates the interaction and proceeds towards the Goal object.

7 VERIFICATION AND VALIDATION

As a first step in understanding the benefit of integrating ABS into a DES model, verification and validation was performed. The focus of this step was on the following questions: "Is the ABM (Computerized Model) accurate to the Conceptual Model presented in the test case?" and "Does the function of the Computerized Model match the expected result of the actual system?".

7.1 Computerized Model Verification

In approaching the first question, both static and dynamic verification techniques (Sargent 2003) were used. Structured walk-throughs were used to ensure that the module was operating correctly in the initial stages of development. This was done by including only a single option that the Seeking Agent was required to take and following the Seeking Agent through its decision pattern. This allowed the authors to verify the Seeking Agent was implementing the decision logic correctly during experimentation, because the correct results were known previous to the experiment being conducted. A repeatability test was also conducted during this verification to ensure there were no unexpected factors affecting the model. Once the logic was operating to the satisfaction of the authors, dynamic verification was conducted.

The dynamic verification was completed by including the random decisions in the model and tracing the Seeking Agent through its decision logic. The operational graphic technique (Sargent 2003) was used to visually illustrate the decision logic used by the Seeking Agent to obtain the goal object. To implement this technique, the decision states of the Seeking Agent (1-11) were recorded during experimentation and were then plotted by time to demonstrate the flow of the agent's decision logic (Figure 3).

In this example, the Seeking Agent first switched between State 1 (searching for an information source) and State 2 (deciding on action) until it found an object it recognized as an information source. The small amounts of time the Seeking Agent was in State 2 represent the decision time the agent required to recognize and record the objects in memory. Once the Seeking Agent recognized that the second object examined was an Informative Agent, the decision state was changed to State 6 (Walk to Moving Object) and the Seeking Agent proceeded to the Informative Agent. When the Seeking Agent arrived at the information source, it took 26 seconds (set as a parameter)

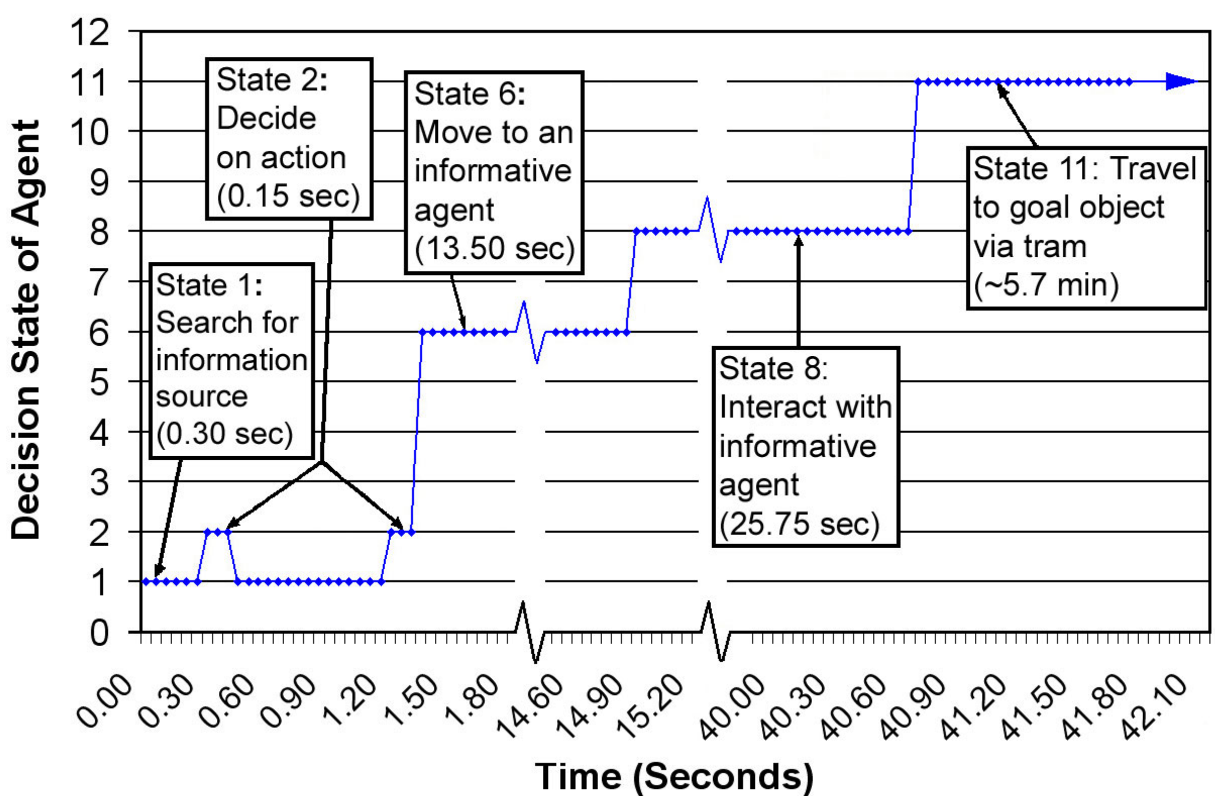

Figure 3: Decision State Logic Flow

to interact with the Informative Agent. The Seeking Agent then proceeded to the goal object (State 11). This flow of this decision logic was deemed to be satisfactory and many more analyses like this were performed to validate the decision logic flow. This process was done several times with the initial position of the Seeking Agent and placement of the other objects in the simulation world begin changed with each run of the simulation. The results of these experiments were as expected, and therefore the model was verified to operate according to the specifications of the conceptual model.

7.2 Subjective System Validation

A subjective validation process was conducted to compare the operation of the module with the expected results from an actual system. The Animation Observation validation technique was used to complete this task. The Animation Observation technique was used to visually confirm that all of the agents' movements and decisions appeared to be realistic. This process was performed with 50 different starting positions and the Seeking Agent performed as expected in all trials. The scenarios observed include:

- Interaction with Informative Object
- Interaction with Informative Agent
- Obtaining Goal Object via tram
- Obtaining Goal Object via walking
- Misinterpretation of information received
- Locate Goal Object without information source
- Emission of verbal signal
- Reaction to verbal signal

Based on this technique the high level agent decision and movement patterns are accurate to the point of visually mimicking the real life system.

8 CONCLUSIONS

The overall purpose of this project was to show that ABS can be integrated with a common DES package to model humans traveling freely through a DES environment. The module was successful in mimicking the decision pattern and movement of individuals navigating the simulation world, without a defined path or decision points. With the defined concept and implementation of this module, the integration can now be used to run experiments that can demonstrate its full benefit.

An example test case demonstrated a potential useful application for this integration. By combining DES and ABS, we were able to simulate aspects of the system that cannot be simulated by either of the simulation methods alone. As work on this project proceeds, real world scenarios will be used so that quantitative validation can be performed to show the actual benefit of this approach.

9 FUTURE WORK

Future work will consist of (a) further validation of model elements, (b) addition of features to the ABM to add accuracy and scope, and (c) applying this model to a real world problem with empirical data.

In building the ABM module, it was found that empirical data on human behavior and decision making are not readily available in a form that is easy to simulate. For example, walking speeds, times for making decisions, and the probabilities of strategies are rarely reported in the literature and need to be further explored.

Our ABM module can be enhanced with several features based on existing literature and some experimentation. For example, individual differences in preference for the display of information, additional object types in the simulated environment and outside of it (as accessible by mobile phones), additional modes of transportation, and additional interactions such as transfer of money in stores and in ATMs.

Once this module is further validated and somewhat expanded, it will be used to model a real-world problem and make decisions concerning factors that affect the agent's behavior

REFERENCES

Banks, J., Carson, J. S. II, Nelson, B. L., Nicol, D. M. 2001. Discrete Event Simulation, Third Edition. Prentice Hall, Inc. Upper Saddle River, New Jersey.

Banks, J., Hugan, J., Lendermann, P., McLean, C., Page, E. H., Pegden, C. D., Ulgen, O., and Wilson, J. R. 2003. The Future of the Simulation Industry. In the *Proceedings of the 2003 Winter Simulation Conference*, eds. S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morric. 2033-2043. IEEE, Piscataway, New Jersey. Available via <http://www.informs-sim.org/wsc03papers/263.pdf> [Accessed March 1, 2005]

Epstien, J. M. and Axtell, R. L. 1996. *Growing Artificial Societies: Social Science from the Bottom Up*. Cambridge, MA.: MIT Press

FIRE SAFETY ENGINEERING GROUP website. 2003. Software Information [online]. Available online via <http://fseg.gre.ac.uk/EXODUS/air.html>[accessed March 1, 2005].

Huberman, B. A. and Glance, N. S. 1993. Evolutionary Games and Computer Simulations. In the *Proceedings of the National Academy of Science* USA 90. 7716-18

Introduction to Swarm website. 2005. Main Page. Available online via <http://www.swarm.org/wiki/Introduction_to_Swarm>. [accessed March 1, 2005]

Law, A. M., and W. D. Kelton. 2000. Simulation Modeling and Analysis. 3rd ed. New York: McGraw-Hill.

Michel, F., Gouaïch, A. and Ferber J. 2003. Weak Interaction and Strong Interaction in Agent Based Simulation. In the *Proceedings of the Multi-Agent Based Simulation III*, eds. D. Hales, B. Edmonds, E. Norling, and J. Rouchier. 43-56. Volume 2927., Springer-Verlag Berlin Heidelberg 2003

Repast Agent Simulation Toolkit website. 2005. Package Overview. Available online via <http://repast.sourceforge.net>. [accessed March 1, 2005]

Sargent, R. G. 2003. Verification and validation of simulation models. In *Proceedings of the 2003 Winter Simulation Conference*, eds. S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, 37-48. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers. Available via <www.informs-sim.org/wsc03papers/006.pdf> [accessed September 1, 2004].

Wickens, C. D., Lee, J., Liu, Y., and Gordon-Becker, S. E. 2004. *Introduction to Human Factors Engineering.* Prentice Hall, Inc. Upper Saddle River, New Jersey.

X J Technologies. 2005. Company Information [online]. Available online via <http://www.xjtek.com> [accessed March 1, 2005].

AUTHOR BIOGRAPHIES

BENJAMIN DUBIEL received his bachelors of science in Industrial Engineering from the University of Michigan in 2005. The work presented here was performed as one of many undergraduate projects. He has nine years of experience with multiple simulation packages including Automod, Arena, and Promodel. His primary interest is using simulation to solve operational problems in transportation, manufacturing, and theme park related fields. His e-mail address is: <ish6868@hotmail.com>.

OMER TSIMHONI is an Adjunct Assistant Professor at the Department of Industrial Engineering of the University of Michigan and an Assistant Research Scientist at the University of Michigan Transportation Research Institute (UMTRI). He received his Ph.D. from the University of Michigan in 2004. His primary research interest is in the application of simulation to cognitive modeling and human factors. His e-mail address is <omert@umich.edu>.