Proceedings of the 1991 Winter Simulation Conference
Barry L. Nelson, W. David Kelton, Gordon M. Clark (eds.)

SLAM II® TUTORIAL

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ABSTRACT

SLAM II was the first simulation language which allowed a modeler to formulate a system description using process, event, or continuous world views or any combination of the three. Since its initial release in 1981, SLAM II has undergone continual development and application. This paper will provide an introduction to the modeling language and describe the most recent developments in SLAM II.

1 INTRODUCTION

SLAM II, the Simulation Language for Alternative Modeling, was the first simulation language which allowed a modeler to formulate a system description using any of three approaches (world views) or any combination of the three. This integrated framework allows the SLAM II user to take advantage of the simplicity of the process-oriented (network) approach and to extend a model with discrete event constructs should the network approach become too restrictive. Continuous variables may be used in conjunction with a network or discrete event model whenever this is the most convenient way to represent system elements. The ability to construct combined network-discrete event-continuous models with interactions between each orientation makes SLAM II an extremely flexible tool for simulation.

Since its introduction, SLAM II has continued to evolve as a result of extensive application. Experience with thousands of models has demonstrated the flexibility of the language, but has also pointed out the ways in which SLAM II could be extended for greater ease of use.

In addition to enhancements to the modeling language itself, the following software has been developed for use with SLAM II:

- TESS (The Extended Simulation System) provides database management for simulation output data and facilities for graphically building models, and analyzing, graphing, and animating model results.
- A Material Handling Extension (MHEX) provides detailed modeling of regular and special resources (cranes, storage areas, automatic guided vehicles, and guidepaths).
- The SLAM II Interactive Execution Environment (IEE) allows the interruption of a simulation in order to examine system status, reassign variable values, step through events, or call SLAM II support routines for debugging or gaming.
- SLAMSYSTEM includes SLAM II in an integrated simulation system for advanced personal computers.

This tutorial will introduce some of the modeling techniques used in SLAM II, illustrated with simple examples.

2 NETWORK MODELING

A simulation model normally begins with a network, or flow diagram, which graphically portrays the flow of entities (people, parts, or information, for example) through the system. A SLAM II network is made up of "nodes" at which processing is performed. SLAM II nodes, shown in Figure 1, provide for such functions as entering or exiting the system, seizing or freeing a resource, changing variable values, collecting statistics, and starting or stopping entity flow based on system conditions. Nodes are connected by branches, called "activities", which define the routing of the entities through the system. Routing may be deterministic, probabilistic, or based on system variables. Time delays on activities may represent processing times, travel times, or waiting times. Entities which proceed from node to node over activities may have unique characteristics, all "attributes", which control their processing. Entities may reside in "files", or ordered lists of entities which are waiting for some change in system status. The graphical framework for representing a network model simplifies model development and communication.

The process of building a SLAM II network model consists of choosing the symbols which can represent system processes, combining them in a diagram which represents the entity flow, and parameterizing the symbols with model-specific data. A single-server queueing model (representing, for example, a workstation) is shown in Figure 2. The network begins with a CREATE node which generates the first job arrival at simulated time 0.0 and continues to generate arrivals at a rate drawn from an exponential distribution. A QUEUE node is used to delay arrivals until the station is available. The station, whose processing time is sampled from a normal distribution, is represented by the ACTIVITY, or branch, following the QUEUE. Upon completion of the activity, a COLCT node records the interval between departure time and the job's arrival time, which was stored in attribute 1. The graphic modeling approach is both quick to use and an effective way to communicate the structure of a model.

Unless the network was constructed using TESS or SLAMSYSTEM, the diagram is then translated into a set of input statements as shown in Figure 3. Each symbol corresponds to an input statement, and each statement may be followed by a comment which describes the processing being performed. The output from this model would

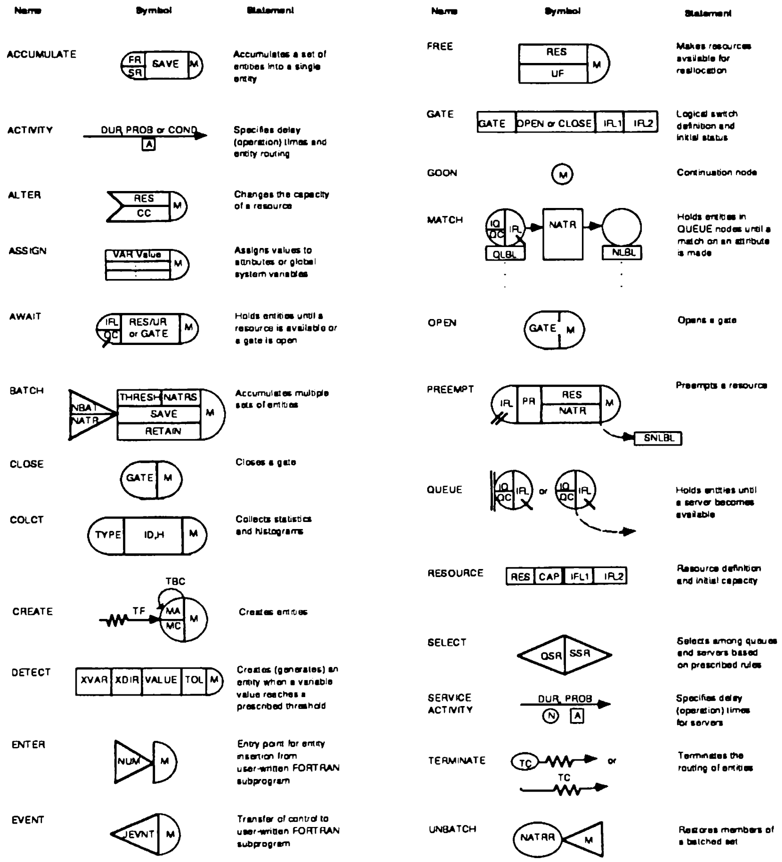

Figure 1. SLAM II Network Symbols

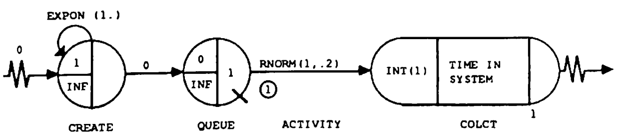

Figure 2. A Single-Server Queuing Example

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CREATE,EXPON(1.),0.,1;              GENERATE ARRIVALS
QUEUE(1);                           WAIT FOR SERVICE
ACTIVITY(1),RNORM(1.,.2);           PROCESS
COLCT,INT(1),TIME IN SYSTEM;        COLLECT STATISTICS
ENDNETWORK
```

Figure 3. Example Model Input

automatically report statistics on job waiting time, queue length, station utilization, time in system and throughput.

3 USING DISCRETE EVENT CONCEPTS

In the discrete event orientation of SLAM II, the modeler identifies the discrete points in time at which the state of the system can change and develops the logic associated with each such "event". SLAM II provides support subroutines which perform such common simulation tasks as scheduling events, moving entities into and out of files, collecting statistics, and obtaining random samples. Most models built with SLAM II are not strictly network or discrete event but a combination of the two approaches.

Several interfaces are possible between a SLAM II network and user-written inserts. One is the EVENT node, which is a "do-it-yourself" node. The EVENT node invokes a user-written subroutine in which highly complex logic may be performed. Support subprograms provide information on system status and allow that status to be changed. Other interfaces to user-written logic provide for complicated variable calculations and sophisticated resource allocation logic.

4 CONTINUOUS MODELING

In a continuous simulation model the state of the system is represented by variables that change continuously over time. The modeler specifies equations which determine the values of state variables and the "step size", or time increment, between the updating of variable values. These equations may be differential equations, in which case the simulator uses a numerical integration algorithm to obtain new variable values from the derivative values.

Continuous variables have proven to be an efficient way to model high-speed, high volume systems such as packaging lines (O'Reilly, 1985). In such a system, a buffer area between two machines may contain several hundred items, too many to be modeled individually. The population of such a buffer is conveniently modeled as a continuous variable which increases at the production rate of the feeding machine and decreases at the production rate of the following machine (Figure 4). The equations defining the rates of change for continuous (SS) variables are written in a FORTRAN subroutine. SLAM II updates the variable values at prescribed time intervals and monitors those variables against any threshold values defined. One threshold value, for example, would be the capacity of a buffer. When it is crossed, the feeding machine would need to cease production until the buffer level decreased enough to accept more production.

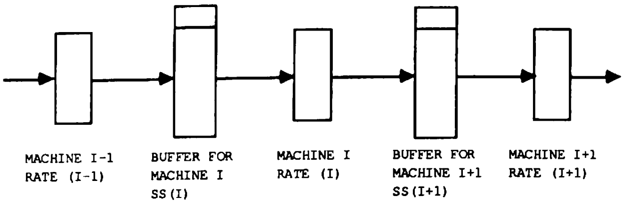

Figure 4. Modeling with Continuous Variables

5 MATERIAL HANDLING MOVEMENTS

Among the most complicated elements to incorporate in a simulation model are automated devices which follow fixed paths. These include overhead cranes, stacker cranes, and AGVS (automated guided vehicle systems). Movements of such devices must be modeled in detail if one is to take into account interference among devices which share a common path. When contention occurs, some way must be found to determine which vehicle will be allowed to proceed. A Material Handling Extension (MHEX) to SLAM II, first available in 1986, provides constructs for simulating these complexities (Pritsker, 1986). Its concepts were derived from several simulation models developed at Pritsker Corporation which required detailed material handling logic.

5.1 Modeling Cranes

An example involving stacker cranes is shown in Figure 5. The schematic depicts a local ASRS system with two stacker cranes serving a lathe and a mill; storage is maintained in nine racks along the crane runway.

The MHEX software takes into account the following complications in this system:

1. Movement times are dependent on crane velocity, distance from destination, and interference with the companion crane.
2. Competing requests for a crane must be prioritized.
3. Storage is limited, and the amount to be allocated depends on the size of an item.
4. If alternative storage locations are possible, selection may be based upon both proximity and material type.

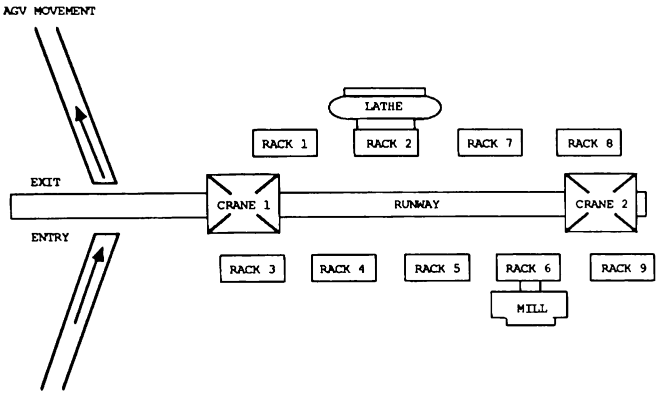

Figure 5. Schematic Diagram of an ASRS System

These interactions are illustrated in the network segment shown in Figure 6. It begins with a GWAIT (generalized AWAIT) node which requests an available rack and crane. Knowing from the RACK definition (not shown) the capacities and locations of the storage areas and where to find the size of the item to be moved, the software will allocate the closest storage location having sufficient space.

Knowing from the CRANE definitions the velocity, acceleration and deceleration of the equipment, and keeping track of both cranes' positions, the software will release the item only when an available crane (CR1 or CR2) can reach the pickup point.

After the item is loaded on the crane, taking 0.5 minutes, a GFREE node releases the pickup point and initiates the crane move. Movement time is calculated internally and is based on equipment speed, distance between the ENTRY and RACK locations, and any interference encountered dynamically. Following transport, 0.5 minutes are required to remove the item from the material handling equipment, and a second GFREE node releases whichever crane was assigned.

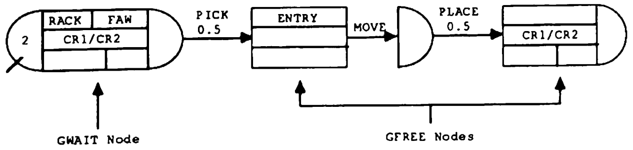

Figure 6. Movement from Entry Point to Storage

5.2 Modeling an AGVS

An Automatic Guided Vehicle System (AGVS) consists of a fleet of vehicles, a guidepath, and a computer control system which determines how a vehicle is selected and routed to a job request. Unlike cranes on runways, AGV's on guidepaths may turn corners and select alternative segments, greatly complicating the logic required to deal with interference and possible alternate routes.

MHEX includes constructs for defining an AGV fleet (number of vehicles, their sizes and speeds) and guidepaths (number of control points, length of each segment, and direction of travel). Once these elements are defined, three node types are used to model the control logic of the system by allocating a vehicle, initiating a move, and releasing a vehicle for reallocation. (Sale, 1987).

6 INTERACTIVE EXECUTION ENVIRONMENT

The SLAM II Interactive Execution Environment provides an interactive user interface to the simulation of a SLAM II model. The modeler may examine, modify, save or load the current system status using the IEE.

The IEE aids a model developer in debugging a model under construction and verifying the completed model. The analyst can use the IEE to develop and analyze alternative control strategies for the system. The what-if questions that arise during model development can be immediately explored using the IEE.

The modeler communicates with the IEE by issuing commands. The commands include:

ADVANCE
BREAKPOINT
CALL
CANCEL
CONTINUE
DIARY
EXAMINE
HELP
LOAD
SAVE
SET
STATUS
STEP
STOP
TYPE

Using the ADVANCE and STEP command the modeler can control how long the model is simulated. With BREAKPOINTs the modeler can simulate the model until a certain state is reached. For example, one could simulate until the number of orders waiting for processing is greater than 6. Using the EXAMINE and SET commands system variables can be viewed and modified.

The IEE is an interactive interface to SLAM II that supports a complete on-line help system. The features of the IEE are fully described in the *SLAM II Quick Reference Manual* (Pritsker, 1990).

7 CONCLUSION

SLAM II is a proven, powerful modeling methodology. It has been used for hundreds of simulation projects and as the basis for simulation courses in many colleges and universities. Published applications (see references) describe models dealing with problems in manufacturing, transportation, material handling, staffing, experimental design, communications systems, and many more.

Continuing development of SLAM II and simulation support software has culminated in TESS and SLAMSYSTEM, integrated simulation systems for workstations and personal computers. SLAM II, TESS and SLAMSYSTEM are distributed by Pritsker Corporation, which offers regularly scheduled training classes as well as applications support.

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