Proceedings of the 1987 Winter Simulation Conference
A. Thesen, H. Grant, W. David Kelton (eds.)

MODELING AGV SYSTEMS USING NETWORK CONSTRUCTS

Michael W. Sale
Catherine W. Stein
Pritsker & Associates, Inc.
1305 Cumberland Avenue
West Lafayette, IN 47906

ABSTRACT

The network world view of SLAM II® has been demonstrated as an effective method for modeling manufacturing processes. An automatic guided vehicle system (AGVS), however, may be difficult because of the special nature of its resources and their activities.

This paper presents the Material Handling Extension for SLAM II© (MHEX). The MHEX overcomes these difficulties through a specialized set of network capabilities. This paper begins by describing the unique requirements imposed by an AGVS model. Next, the MHEX modeling approach is presented relative to these requirements. The paper is concluded by an example which emphasizes the use of the MHEX and how it is integrated with SLAM II.

1. BACKGROUND

The use of automatic guided vehicles in manufacturing facilities is expanding at a rapid rate. AGV technology promises tighter material control and WIP reduction. In addition, an AGVS can reduce operating expenses and MH floor space requirements.

A successful AGVS implementation, however, is not easily achieved. Its designers must carefully consider many issues, including those listed below.

1. Since the AGVS is integral to the larger manufacturing system, its performance is directly related to that of the total system. Thus, the AGVS cannot be independently designed and its design requirements must be correctly understood.

2. Reduced WIP reduces the tolerance for MH delays. Some delays are inevitable, however, due to vehicle interference, system loading dynamics, and AGVS hardware and software limitations. Thus, a successful design must balance fleet size, guidepath layout, input and output queue size, and system control considerations.

3. An AGVS implies less (direct) human involvement at the operations level. Thus, the control software must be designed and tested assuming a range of production loads and operating contingencies.

2. AGVS MODELING - A NETWORK APPROACH

Simulation modeling is playing an increasingly important role in the resolution of AGVS engineering issues. To facilitate these model developments, Pritsker & Associates, Inc. (P&A) provides the Material Handling Extension for SLAM II (MHEX).

Basically, the MHEX is a complement of specialized capabilities that augment the SLAM II network world view. It provides nodes and resources that address both the physical and the control logic aspects of an AGVS. It is fully integrated within the SLAM II modeling framework, and that of TESS™ (The Extended Simulation Support system) which provides statistical and graphical analysis capabilities.

The following features highlight the advantages of the MHEX's network orientation.

1. The physical guidepath layout is easily represented as a system of specialized resources. This is especially important when many candidate layouts are to be evaluated or when a layout is in a constant state of change.

2. Specialized nodes are provided to facilitate AGV dispatch, delivery and empty movement control. "Shortest path" vehicle routing is an automatic feature.

3. The control system is typically the most difficult (and crucial) aspect of an AGVS model. This is facilitated by an extensive set of user selected symbol parameter options. Since the MHEX cannot anticipate all conceivable control strategies, the software provides the ability to "drop" into the SLAM II discrete event world view. This allows the user to code the required logic rules using FORTRAN.

4. The network orientation has been proven to reduce model development and verification time. In addition, network models are more easily learned, transferred and maintained.

The following section presents the characteristics of a typical AGVS as a basis for understanding the required modeling level-of-detail. This is followed by a brief MHEX tutorial: each construct is presented relative to the system aspects it represents. The paper is concluded by an example which emphasizes the use of the MHEX and its integration with SLAM II.

3. AGVS DEFINITIONS

The following example illustrates the need to represent the physical characteristics of an AGVS, vehicle movement and AGV fleet control. This serves as an introduction to a more detailed treatment by sections to follow.

The manufacturing system shown in Figure 1 consists of six identical machining cells, a fixture station (SFIX) and an AGVS. The AGVS consists of two vehicles traveling on a uni-directional guidepath, with the exception of the bi-directional load/unload spur. Each machine is capable of handling (and storing) only one part at a time.

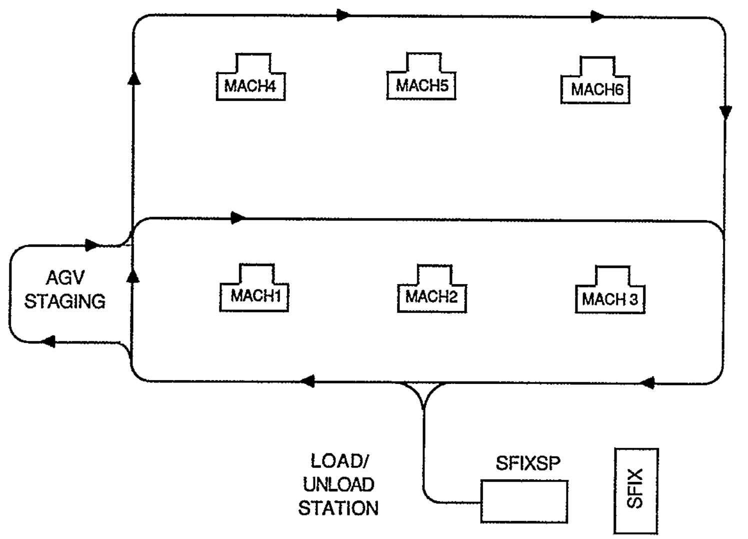

Figure 1. Schematic Diagram of Manufacturing Cells with an AGVS

Castings are machined by the system according to the following sequence.

1. Castings are mounted onto a fixture at the fixture station.

2. Mounted castings are indexed onto the AGV load station and wait for machine availability in FIFO order. The load station is limited to five castings before the fixture station becomes blocked.

3. The first waiting casting requests AGV pick-up in the event an empty and idle machine is available.

4. The first available AGV is dispatched by the AGVS. The closest vehicle is assigned if both vehicles are available at the request time.

5. Upon AGV arrival, the casting is loaded and transported to the destination machine using the shortest (distance) route.

6. Upon arrival to the machine, the casting is unloaded and begins machining. The AGV is freed following unload. At this time, the AGV may be dispatched to a pending request, or is otherwise directed to the AGV staging area.

7. The machined casting is returned to the fixture unload station using a similar AGV "dispatch-load-transport-unload-release" sequence. (The AGVS prioritizes machined castings over unmachined casting requests. Secondary ranking is closest first.)

8. The casting is unloaded upon arrival to the unload station where it waits to be dismounted at the fixture station.

3.1 AGVS Physical Characteristics

Physically, an AGVS is comprised of vehicles, guidepaths and control (communication) points. Guidepaths define a vehicle's path. They may be installed as wire underneath the surface of the floor through which radio signals are sent, or by other visual or chemical means. Guidepaths may be uni-directional or bi-directional. The number of vehicles simultaneously resident on a guidepath segment can be limited.

Vehicles travel along guidepaths to reach destinations at rates depending on the acceleration, maximum speed, and deceleration of the vehicle unit. The maximum speed may be different depending on whether the AGV is loaded or traveling empty. It is possible that more than one vehicle type is resident within a given guidepath layout. Each homogeneous vehicle group is known as a "fleet."

Vehicles are controlled by either a central computer, an on-board computer, or a combination of the two. Communication points are located at various guidepath positions in the event a central computer is used. These points define locations where a vehicle's position and status are reported, and routing and job assignments are received. Included are: load and unload stations, guidepath intersections, and the boundaries of guidepath segments having limited capacity.

3.2 AGV Movement Characteristics

In general, material transport is accomplished by the following sequence of activities:

1. Unit load requests pick-up at a given control point location.
2. The job is assigned an AGV.
3. The vehicle is dispatched to the waiting job.
4. The vehicle stops and is loaded.
5. The vehicle travels to the job's destination.
6. The vehicle is unloaded.
7. The vehicle becomes idle: it is either assigned a new job or it is routed according to a specified idle logic.

The vehicle's travel time is therefore dependent on the initial position of the vehicle, its pick-up location and its drop-off destination. In addition, a vehicle may encounter portions of the guidepath which are congested by slower moving AGV traffic, traffic at intersections, stopped vehicles, and interference from other MH devices.

3.3 AGVS Control System Characteristics

The control system instructs a vehicle to travel to a particular control point and specifies the route to be used. The control system is also responsible for prioritizing job assignments. For example, the control system must select a vehicle to service a job in the event more than one vehicle is available. Conversely, it must assign a job to an AGV in the event more than one job is requesting service at the instant a vehicle becomes free. In addition, the control system is responsible for all traffic management activities.

4. MATERIAL HANDLING EXTENSION TUTORIAL

As previously introduced, the MHEX provides a specialized set of resources and nodes to represent an AGVS. These symbols are consistent in use and in syntax with the standard SLAM II network world view. Table 1 summarizes these constructs and their associated parameters.

4.1 AGVS Resources

Two resource types (VSGMENT and VCPOINT) are used to define the guidepath segments and the control points which comprise the physical AGVS layout. A third resource type (VFLEET) is used to define each vehicle fleet in the system. The MHEX software uses this information to continually track the position, destination, and status of each AGV within each vehicle fleet. The software also maintains an accurate status of each guidepath and control point resource.

An AGV guidepath can be broken into "segments" bounded by "control points". Control points may be load or unload stations, intersections or communication points.

A VSGMENT resource block is used to define the characteristics of each segment using length, capacity and directionality parameters. The segments are logically joined using parameters which define the VCPOINT resources of each segment's endpoints.

Correspondingly, a VCPOINT resource block is used to describe each control point's battery charging capability, as well as the control logic used for vehicle routing and contention. The "shortest path" feature is one vehicle routing option. The user programmed option "URROUT(NR)" is provided if an alternative strategy is required. Similarily, the control system must resolve vehicle contention which occurs when more than one vehicle is waiting to enter a VCPOINT in the event it becomes free. The contention options include the ability to prioritize vehicles based on their load status, distance from their destination control point, or accumulated waiting time.

Physical characteristics of a vehicle fleet are defined by the VFLEET resource block. These include acceleration, deceleration, length, and the maximum speeds attainable when traveling empty and loaded. Logic for job selection and idle vehicle routing is also required. The MHEX provides two (default) strategies for positioning idle vehicles: travel and stop at a specified VCPOINT, or "cruise" a circular route (as specified by the sequence of VCPOINT resources to be visited) until requested.

4.2 AGV Network Elements

Corresponding to the specialized resource blocks, the MHEX provides a node set representative of material transport. In the context here, entity flow represents unit loads requesting transport from one control point (load station) to another (unload station). Control of this process is provided by the VWAIT, VMOVE and VFREE nodes as described below.

Figure 2 presents a typical AGVS transport sequence for purposes of discussion. Its corresponding node sequence is also shown.

An entity arriving to the VWAIT node requests transport by an AGV from fleet "VEHICLE" located at control point "FROM-CPT". As a result, an idle vehicle resource is assigned and dispatched according to the rules specified by the appropriate VFLEET and VCPOINT resource blocks. The routing and travel time are automatically calculated. Travel time is dependent on the VFLEET parameters, AGV location and guidepath congestion. The entity is released from the VWAIT node when the AGV arrives at "FROM-CPT".

A regular SLAM II activity defines the time required to load the entity onto the AGV. The transport activity to the destination VCPOINT "TO-CPT" is initiated by the VMOVE node. Again, the routing logic is defined by the VCPOINT resource blocks. When the AGV reaches its destination, the entity is released from the VMOVE node.

The unload process is represented using another SLAM II activity. Following unload, the AGV resource is released at the VFREE node. Upon release, the "VEHICLE" resource is assigned a pending (VWAIT) request, or otherwise assumes an "idle logic" as specified by its VFLEET block.

Table 1. MHEX Symbol Descriptions

SYMBOL	PURPOSE	PARAMETERS
VCPOINT	Define control point resource	Index and label identifiers Vehicle contention rule - FIFO, CLOSEST, PRIORITY, URCNTN(NR) Vehicle routing rule - SHORT, URROUT(NR) Battery charging capability
VSGMENT	Define guidepath segment resource	Index and label identifiers Boundary control point identifiers Segment length Directionality Capacity (# vehicles)
VFLEET	Define AGV fleet resource	Index and label identifiers Number of vehicles in fleet Maximum speeds when empty and loaded Acceleration/deceleration Vehicle length Distance buffers on segments and at intersections Job request file Job request prioritization logic - PRIORITY, CLOSEST, URJREQ(NR) Idle vehicle routing logic - STOP (CPNUM list), CRUISE (CPNUMLIST), URIDL(NR) Output reporting options
VWAIT	Dispatch AGV to requesting entity	File # for waiting entities Requested vehicle fleet identifer Location of entity requesting transport (control point identifer) Vehicle request rule - FIFO, CLOSEST, URVREQ(NR) Entity release rule - TOP, MATCH, UREREL(NR) Maximum # of activity selections
VMOVE	Transport entity to specified destination	Destination control point Maximum # of activity selections
VFREE	Release servicing AGV resource	Vehicle fleet identifier Maximum # of activity selections

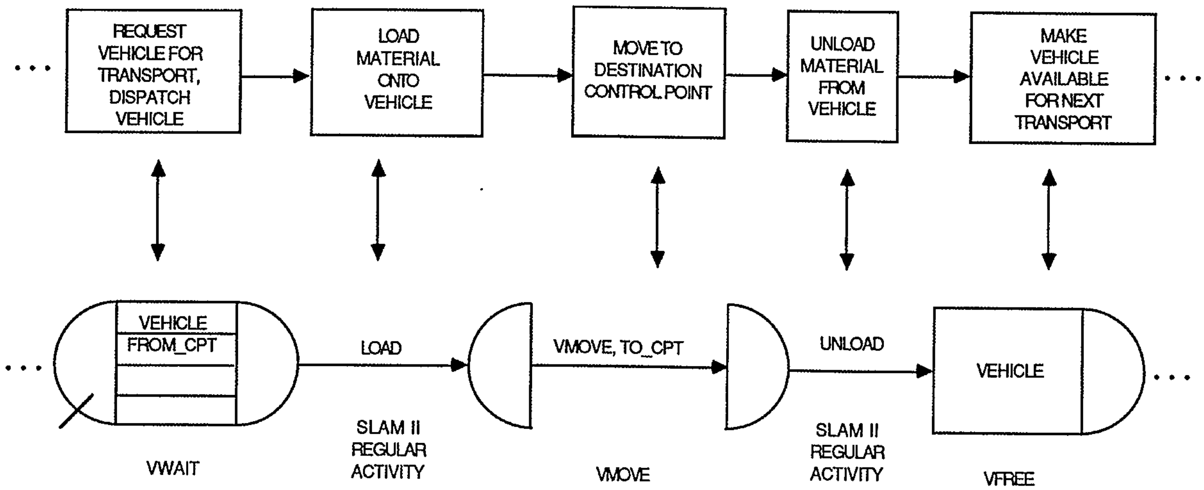

Figure 2. Typical AGVS Transport Sequence

5. EXAMPLE AGVS MODEL

The manufacturing system introduced by Figure 1 can be modeled using the MHEX and SLAM II. Basically, SLAM is used to model the fixture station and the machining cell dynamics. The MHEX is used to model the AGVS.

Model conceptualization is facilitated by numbering each segment and control point as shown in Figure 3. Correspondingly, Figure 4 presents the resource blocks which describe the physical system. VCPOINT resource blocks are constructed for each load and unload station (1, 7, 8, 9, 11, 12, and 13). The intersections are also defined as control points (2, 3, 5, 6 and 10) with their associated vehicle contention logic. VSGMENT resource blocks describe the guidepath segments. Segment 1 is bi-directional; all others are uni-directional. Since the two AGVs are identical, only one VFLEET resource block is required. Regular SLAM II resources represent the fixture station and machining cells.

The network diagram used to represent casting flow is presented in Figure 5. The assigned machining cell and its corresponding control point identifier are tracked for each (casting) entity using ARRAY and entity attribute capabilities. Thus, attribute-based delivery and vehicle dispatch are used to significantly reduce the number of nodes required. Casting transport is modeled using two repetitions of the previously discussed transport sequence. These are recognized by the sequences beginning with VWAIT nodes VW06 (load station to machine) and VW10 (machine to unload station). Standard SLAM II nodes handle allocation of the fixture station and machining cell regular resources, as well as collection of "time in system" statistics.

Upon completion of model execution, a SLAM II summary is generated. The following reports are provided in addition to the standard file, resource, and activity statistics: a trip report matrix, segment statistics, control point statistics, and a vehicle utilization report. A detailed AGV trace for model verification and debugging is also available.

6. DETAILED CONSIDERATIONS

The comprehensive set of network options provided by the MHEX can be used to represent AGVS control logic in most situations. However, some complex systems may require application-specific procedures for vehicle selection, routing, contention or load selection. The user written subprograms summarized by Table 2 can be used in these instances.

To facilitate FORTRAN coding, a library of 16 MHEX subprograms provide access to the AGVS status. For example, current AGV location, number of vehicles on a segment, and AGV destination are accessible through subroutine calls.

7. SUMMARY

The MHEX provides a significant advancement of the SLAM II general purpose language. Since the MHEX is tailored to AGVS applications, minimal discrete event programming is required. In addition, the network orientation facilitates model development, verification, communication and change. This results in a more timely and thorough AGVS analysis. This view is supported by P&A's Applications Staff and its outside users who have successfully applied the MHEX on numerous projects.

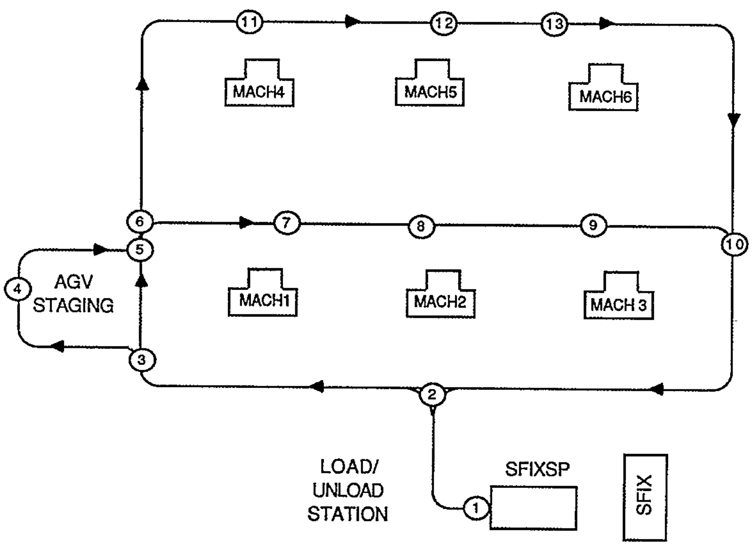

Figure 3. Schematic Diagram with Resource Labels and Numbers

VFLEET								
AGV1	2	4.5	4.0	0	0	4.0	4.5	2.0
6/CLOSEST	STOP(4)			4(2,4)				
								YES

RESOURCE		
MACH 1	1	3
MACH2	1	3
MACH3	1	3
MACH4	1	3
MACH5	1	3
MACH6	1	3
SFIX	1	1
SFIXSP	5	2

VC POINT			
1/FIXTURE	FIFO	SHORT	NO
2	FIFO	SHORT	NO
3	FIFO	SHORT	NO
4/STAGE	FIFO	SHORT	NO
5	FIFO	SHORT	NO
6	FIFO	SHORT	NO
7/MACH1	FIFO	SHORT	NO
8/MACH2	FIFO	SHORT	NO
9/MACH3	FIFO	SHORT	NO
10	FIFO	SHORT	NO
11/MACH4	FIFO	SHORT	NO
12/MACH5	FIFO	SHORT	NO
13/MACH6	FIFO	SHORT	NO

VSGMENT				
1	1	2	20	BI
2	2	3	82	UNI
3	10	2	115	UNI
4	3	4	27	UNI
5	3	5	16	UNI
6	4	5	27	UNI
7	5	6	13	UNI
8	6	7	35	UNI
9	7	8	35	UNI
10	8	9	35	UNI
11	9	10	35	UNI
12	6	11	75	UNI
13	11	12	35	UNI
14	12	13	35	UNI
15	13	10	75	UNI

Figure 4. Resource Block Definitions

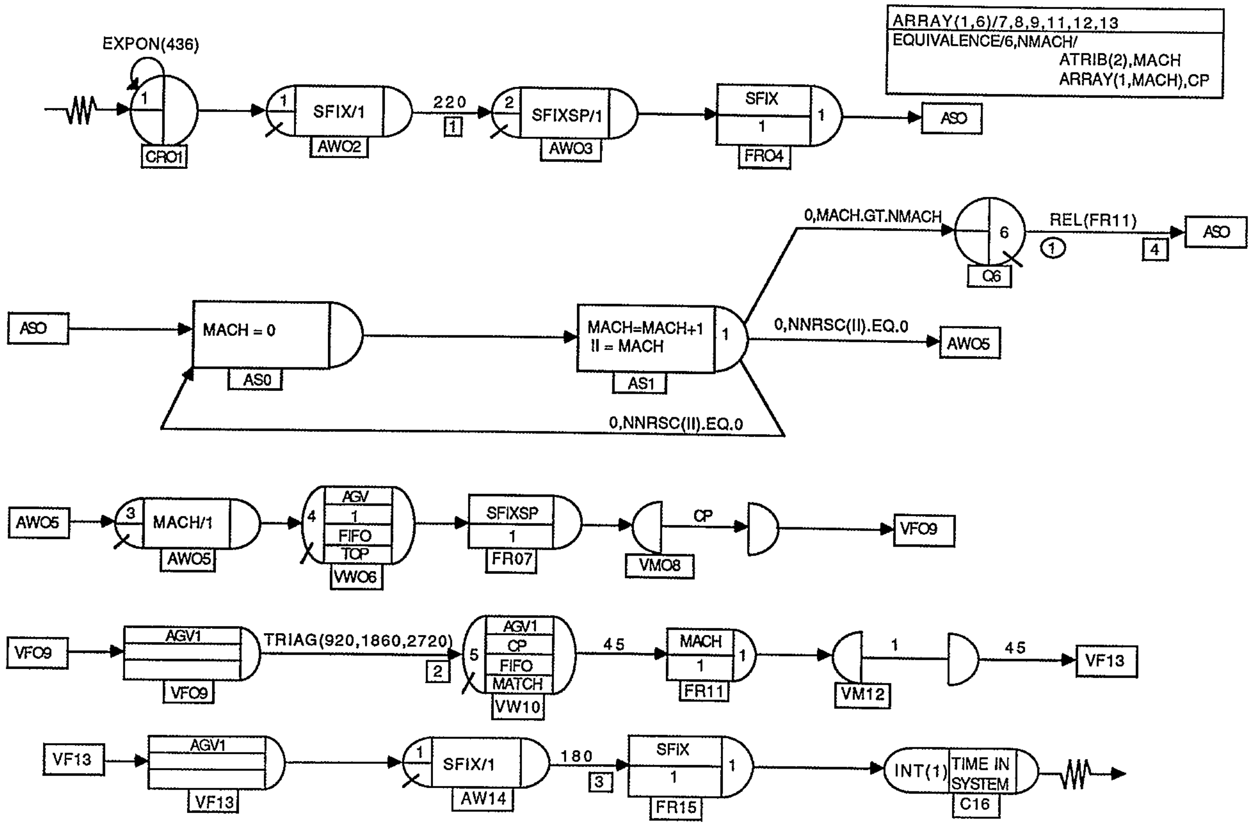

Figure 5 Network model of manufacturing cells with an AGV.

Table 2. USER-WRITTEN SUBPROGRAMS

SUBPROGRAM	EXAMPLE NEED	REFERENCING CONSTRUCT	CALLING EVENT
UREREL	Dynamic prioritization of jobs after vehicle is dispatched	VWAIT	AGV arrives to requesting control point
URVREQ	Vehicle selection based on system status	VWAIT	Load requests transport and more than one vehicle is available
URJREQ	Job selection based on system status	VFLEET	AGV completes a job
URIDL	Idle vehicle routing based on current vehicle location	VFLEET	AGV becomes idle
URCNTN	Dynamic prioritization of AGVs waiting to enter a control point	VCPOINT	Control point becomes free and more than one vehicle is awaiting entry
URROUT	Next segment to be traversed from a control point is not necessarily on the shortest path route	VCPOINT	AGV reaches the control point (non-destination control points only)

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AUTHOR'S BIOGRAPHIES

MICHAEL W. SALE is a Senior Systems Consultant with Pritsker & Associates, Inc. He holds a Bachelor of Science degree in Industrial Engineering from the Rochester Institute of Technology and a Master of Science degree from Oklahoma State University. During his six year tenure at P&A, Mr. Sale has successfully applied simulation to evaluate numerous discrete and continuous manufacturing systems. He presently leads a staff of consultants dedicated to applications within the consumer products sector.

CATHERINE W. STEIN is a Senior Systems Analyst with Pritsker & Associates, Inc. She holds a Bachelor of Science in Industrial Engineering from Purdue University. Since joining P&A, Ms. Stein has applied SLAM II and the Material Handling Extension to a variety of consulting projects. Her current responsibilities include user support and training for P&A software products.

Michael W. Sale
Catherine W. Stein
Pritsker & Associates, Inc.
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