SIMULATION MODELING OF MATERIAL HANDLING SYSTEMS - REQUIREMENTS AND COMPARATIVE ANALYSIS

by

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Simulation Modeling of Material Handling Systems - Requirements and Comparative Analysis

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(ABSTRACT)

This thesis identifies various material handling model parameters which must be addressed when using simulation. Operations of six material handling devices (AGVS, AS/RS, conveyors, cranes, fork trucks, and industrial robots) are studied to determine attributes which require modeling consideration.

Four simulation software packages (GPSS, PROMODELPC, SIMAN IV, and SLAM II) are analyzed to determine their capabilities for modeling material handling situations. A survey was developed to extract information, from software experts, about each software package under study. Based on this survey, the state-of-the-art in modeling materials handling systems is assessed.

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I dedicate this thesis to all of my loved ones. Especially, to my father and mother, Mr. & Mrs. William Comer, Sr. They have always pushed me to do my best and their teachings have molded me into who I am today. To them I sincerely say thank you. I'd also like to express my sincere gratitude to my boyfriend, Kirk Keyes. Thank you for standing by me through the past two years. Though the miles have been difficult, you never gave up on us. Thank you to my entire family for supporting me in my endeavors.

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1.0 INTRODUCTION

1.1 OVERVIEW

Simulation is used more widely than ever due to the advances in computer power. Only years ago, it was necessary to run simulations on mainframes, but now literature suggests that personal computers are the dominant platform.

There are many simulation packages on the market today. Deciding which is best for a given task can be very difficult. Many of these packages claim they have the solution for modeling complex systems with ease. This research examines various PC-compatible simulation packages which model manufacturing systems. The focus of this research is on the material handling component of manufacturing systems. Many of these systems also have modeling constructs designed specifically to address complicated material handling movements.

Material handling is an essential element of most manufacturing systems. It involves the use of devices (i.e. AGVS, conveyors, robots, etc.) and people to promote material movement. The various material handling devices can be unreasonably difficult to model using many simulation languages. Therefore, many simulation packages have emerged into the market with constructs designed specifically to better meet the needs of many manufacturing systems. SIMAN, SLAM, GPSS and PROMODEL are simulation packages which have recognized the complexities of modeling manufacturing systems. These four simulation packages are some of the most widely used simulation methods in the U.S. today. Most of these packages also offer modeling features which should decrease difficulties in modeling materials handling systems.

1.2 Statement of Problem

Material handling systems have experienced a rapid increase in sophistication and complexity over the past decade. Thus, modeling these systems has, in effect, become more difficult. Many users of simulation packages are aware of the inevitable difficulties in modeling materials handling components. Simulation software developers have not yet addressed all of the modeling complexities found when modeling these materials handling systems.

This research will identify characteristics of various material handling devices which should be addressed by simulation software developers. Further, by identifying the subset of those characteristics which are currently difficult to model, software developers will know where to direct their attention when developing material handling constructs. By identifying the characteristics of various material handling devices, software users (modelers) will know what complexities they may encounter when modeling such systems.

By comparing the various software packages, a clear statement of the material handling capabilities of each package is presented. Users are able to better determine the compatibility of a given software package with their material handling modeling requirements. Developers benefit in knowing the possible limitations of their software, because it identifies opportunities for improvement and development.

Two major problems are addressed by this research. The problems are stated as follows:

- o Simulation software developers are often not adequately in tune with the needs of engineers and others who use their product for material handling issues. Developers must realize and understand the modelers needs.

- o We as users are often unaware of the actual material handling capabilities of a given software system prior to purchasing. Though many software packages advertise special material handling features, they may not be enough to properly model the complexities of a given material handling system.

Banks, Aviles, McLaughlin and Yuan (1991) state, "As vendors realize simulator's [simulation software's][1]

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1 brackets added

limitations, they can begin to eliminate them in succeeding versions of their software." Likewise, vendors (developers) realization is a direct result of users notification. There must be more interaction between users and vendors to experience faster and greater technological advances in simulation technology.

1.3 Objective

This research has a two part objective. First, it identifies attributes that one may want to model for unit load material handling devices (AGVS, AS/RS, cranes, conveyors, robots and industrial trucks). Second, it assesses the existing modeling capabilities of four well known simulation software packages.

This research assesses the state-of-the-art in modeling material handling systems using four computer simulation software products (SLAM, GPSS, PROMODEL and SIMAN). Material handling is prevalent in almost all manufacturing systems. It ofttimes comprises the majority of activity within a manufacturing system. This research retrieves and presents valuable information from a group of experts. This information should aid modelers in determining the best simulation package for their materials handling system.

In addition to aiding modelers, this paper also aids developers of future simulation packages. Many developers have recognized complexities in designing a simulation package which accurately and adequately models many variations of material handling systems. Therefore, another objective of this research is to determine the basic elements which are necessary within a simulation package to properly model discrete event material handling systems.

The objectives may be summarized in the following statements.

- Define operating logic inherent in various material handling system which must be addressed when modeling such systems using simulation.

- Identify material handling capabilities and limitations of GPSS, SLAM, PROMODEL and SIMAN to assess the state-of-the-art in modeling materials handling systems.

This paper first gives a literature review of simulation, material handling, and the four simulation packages under study. Work done in this area and the methodology for analyzing the languages are also discussed. The actual research experiment and results are displayed in detail in later chapters.

1.4 PROBLEM SIGNIFICANCE

Materials handling may be responsible for 30-75%, or more, of the costs associated with manufacturing a product [Kulwiec, 1985]. This fact alone necessitates accurate modeling of material handling functions when using simulation or any other analytical technique. Materials handling is a vital function in many manufacturing facilities and must be treated as such.

Simulation is described as being "the most versatile and widely used" analytical technique for design and analysis of material handling systems [Kulwiec, 1985]. The flexibility offered by simulation allows the modeler to represent various situations and solve many materials handling problems.

Simulation attempts to model the routing of parts throughout the system [Banks, Aviles, McLaughlin,Yuan, 1991]. Any progressive simulation software used in the manufacturing arena, must address issues of material handling. Law and Haider (1989) state though many vendors have noted the significance of modeling materials handling systems, the diversity of today's material handling systems complicates the ability to model such system. Thus, existing material handling features in simulation software packages are not always sufficient. Therefore, it is important to display the capabilities and boundaries of existing systems, to alert purchasers prior to acquiring an extensive system.

Often, there exists a gap between software developers and modelers of manufacturing systems. It is imperative that developers constantly address the ever-changing needs of simulation users. Today's manufacturing simulation user desires effective, uncomplicated means of modeling a vast array of material handling devices and complex movements of these devices. It is important to define these complex movements, so developers will take steps to alleviate existing problems in modeling these systems. Thus, this analysis may enhance existing simulation modeling capabilities. This will bring simulation a step closer to being an effective analysis technique at the fingertips of more manufacturing decision makers.

Exposing boundaries of existing systems and defining modeling capabilities will allow software developers (vendors) to enhance existing simulation modeling capabilities. It provides a degree of focus to software developers. Developers will know where to direct their attention. Comparing the various software packages may also increase competition in the software development arena, thus creating better simulation products for users.

2.0 LITERATURE REVIEW

This section presents issues which are relevant to the research topic. In order to have a full understanding of the research topic, one must understand various concepts in the areas of simulation and material handling. Past works in the area of simulation software comparison and selection are cited and an overview of each simulation software is given.

2.1 SIMULATION WITHIN MANUFACTURING

Simulation may be defined as the use of a model to imitate the behavior of a given system in an effort to better understand the performance of that system under various circumstances. Simulation is a valuable tool within the manufacturing environment. It is most often used as an experimental tool or decision aid. It has grown in popularity in recent years due to its constantly increasing ease of use, its ability to analyze a vast array of systems, and its ability to economically aid in making relatively sound decisions.

2.1.1 Purposes and Benefits of Simulation

Simulation allows its user to model the real system and perform experiments on the model using a computer. Through these experiments, the user may make inferences about a proposed or an existing system. Computer simulation may be used for the analysis of procedures, design of new systems and evaluating performance of a given system. In the manufacturing context, simulation may answer capacity concerns (i.e. How many machines are required?), evaluate proposed solutions and predict future events. It is also useful in troubleshooting (i.e. Determine the location of the bottleneck [Thesen & Travis, 1990]).

Simulation provides immeasurable benefits for users within a manufacturing environment.

- o By designing a given system, using simulation, one gains a greater understanding of the system being modelled.

- o It is an economical means for performing what-if scenarios.

- o One may experiment with existing systems without interrupting or destroying them.

- o It provides assurance, before creating a system, that a proposed design will meet requirements.

- o It may result in a cost savings for the system being modeled.

There are definitely more advantages of simulation. These are simply some of the most prevalent.

2.1.2 General Purpose Languages, Simulation Languages and Simulators

SLAM, SIMAN, and GPSS are simulation languages and ProModel is often referred to as a manufacturing simulator. In other words, all software under study was designed specifically for the simulation of systems. Simulation languages and simulators are most often utilized in the simulation of systems. Today, developing simulation models solely with general purpose languages is seldom practiced.

General purpose languages (i.e. BASIC, FORTRAN, PASCAL) may be used in various programming situations, thus, they are often much harder to use for simulation purposes. There are several reasons why modelers use simulation languages or simulators rather than general purpose languages.

- o The modeler forsees frequent and/or large modeling requirements.
- o They provide modeling constructs to make development of the model easier.
- o They require minimal statistical collection efforts and results are displayed.
- o The time necessary for modeling is drastically reduced.
- o Debuggers are constructed into the computer system.

These complexities make the use of general purpose languages undesirable. Thus, simulators or simulation languages are most frequently used to simulate systems.

The simulation language or simulator utilized is determined by many factors. The modeler's computer skills and knowledge of simulation languages are definitely a factor when determining which to use. Other factors which govern the selection of one simulation means over another are as follows:

- o Availability of simulation packages and computer resources.

- o Documentation and technical assistance available.
- o Associated costs.
- o Time allotted for modeling efforts.
- o Size and depth of the model.

2.1.3 The Process of Simulation Modeling

According to A. Alan B. Pritsker, the developer of SLAM (Simulation Language for Alternative Modeling), it is necessary to develop a simple model based on problem-solving requirements. The methodology proposed by Pritsker is as follows:

1. Define the problem and state objectives.

2. Formulate the system into a mathematical-logical state based on problem statement.

3. Acquire pertinent data.

4. Duplicate model using computer simulation.

5. Verify proper execution of computer program.

6. Ensure correspondence between the real system and the simulation model.

7. Determine experimental conditions necessary based on desired information.

8. Execute simulation model to determine output.

9. Analyze results. Make recommendations to solve problems based on inferences.

10. Implement decisions made and document the model.

This ten step procedure is valid when using any type of simulation language, general programming language or simulator [Pritsker, 1986].

2.2 MATERIAL HANDLING

The following definition for materials handling is given in the second edition of the Materials Handling Handbook,

> "Materials handling is a system or combination of methods, facilities, labor, and equipment for moving, packaging, and storing of materials to meet specific objectives [Kulwiec, 1985]."

According to the handbook, material handling must be defined in context of a system, because the material handling component has a significant impact on many other components within a system.

According to Apple(1977), material handling could very easily consume 50 to 70 percent of actual production activity. This statement alone implies that material handling is a vital part of manufacturing systems. Material handling may account for over 60% of the cost of making a product [Eade, 1989]. It is crucial to the survival of many business to reduce labor costs and deliver products faster and more efficiently at the lowest cost possible. Due to the demands of accuracy, quality, and just-in-time (JIT) concepts, manufacturers must incorporate efficient material handling of raw material, work in process, and inventory to compete with today's industries. The efficiency of a company's material handling system is directly related to the productivity (output/input) of the company.

2.2.1 Simulation of Material Handling Systems

Many are finding simulation to be a valuable tool for analyzing material handling systems. It is indeed the most widely used and most versatile analytical technique for manufacturing systems. Simulation offers a realistic, real-time method of modeling such systems. Over the years, material handling systems have grown in complexity and sophistication. Simulation is also becoming more user-friendly and may be specialized for manufacturing systems. All of these reasons make simulation a very good means of designing and analyzing material handling systems.

2.2.2 Unit Material Handling Devices

Materials handling systems may involve the act of humans performing material handling procedures or the use of more complex automated components. There exist numerous material handling devices. In an effort to narrow available possibilities, this research paper will focus on automated unit material handling devices. Unit material handling involves the movement of discrete, individual loads or items. This research will focus on the ability of simulation packages to model the following automated material handling devices:

- Powered Industrial Tools (Trucks)
- Automatic Guided Vehicles (Agvs)
- Automate Storage and Assembly Systems (AS/RS)
- Conveyors
- Cranes

- o Robots
[Kulwiec]

Each of these material handling devices is classified as unit material handling devices by Kulwiec's Materials Handling Handbook.

2.3 Simulation Software Selection, Comparisons and Uses

Much research has been performed in the area of simulation and manufacturing systems rather than material handling systems. Many articles address simulation software selection. Surveys have been conducted to determine or define appropriate software for manufacturing systems. Though work has been done in the research area, the exact research issues of this study were not addressed.

Law and McComas (1989) discuss pitfalls one must avoid when modeling manufacturing systems. They address issues such as model development, modeling system randomness, and software use and selection. When selecting or using software, Law and McComas state that flexibility is a major issue. Software must be flexible enough to model a vast array of systems, yet remain relatively user-friendly.

Law and Haider (1989) discuss six features which were found to be desirable when selecting simulation software for manufacturing applications. The inclusion of material handling modules was definitely one of those six important features. They state that there is a need for modeling AGVS, conveyors, robots, cranes, and AS/RS with ease and flexibility. Other features which were declared desirable were general features (execution speed, modeling flexibility, ease of model development, etc.), animation capabilities, statistical capabilities, customer support, and output reports (standard and tailored).

A vendor survey was also performed of several simulation languages and manufacturing simulators. This survey included the four simulation packages under study. The survey basically served to notify users of features offered by each simulation package and costs. Various issues relative to the six features previously discussed were briefly addressed for 22 simulation packages and manufacturing simulators. The following table gives a summary of the material handling modules present in the four systems under study [Law & Haider, 1989].

Table 1.1: Material Handling Modules (information from Law & Haider, 1989)

	GPSS/PC	SIMAN	SLAM II	PROMODEL
Conveyor		Yes		Yes
Forklift		Yes		Yes
AGVS			Yes*	Yes
AS/RS			Yes*	Yes
Cranes		Yes	Yes*	Yes
Robots				Yes

* Using SLAM's Material Handling Extension (MHE)

In 1986, Haider and Banks stated that there were over 100 simulation software products available, therefore, selection of the appropriate software is complicated and crucial. They also state desirable features in selecting simulation software and once again material handling modules are among those features.

In 1982, a study was performed by Abed to evaluate and compare GPSS/H, SLAM, and SIMSCRIPT II.5. A hypothetical model was developed and criteria was stated on which the author based his conclusions. Based on findings, GPSS was the best language for modeling manufacturing systems. This study was based on CPU and memory utilized, execution speed, and rates of change in execution [Abed, 1982].

Banks, Aviles, McLaughlin and Yuan (1991) compared four simulators, SIMFACTORY, XCELL+, WITNESS, and ProModelPC. The results showed that ProModelPC was the only simulator with special constructs for material handling devices. It was also the cheapest of the simulators under study.

Law and Kelton (1991) discuss a comparison of simulation languages performed by the authors and by other researchers. These authors state that GPSS, SIMAN and SLAM II have constructs which are adequate for queueing orientations. SIMAN and SLAM II, unlike GPSS, contain constructs which make it possible to model non-queuing-oriented systems. According to Law and Kelton, a study was performed using GPSS/H, SIMAN, SIMSCRIPT II.5, and SLAM II to model the same manufacturing system. Law and Kelton (1991) provide various tables comparing the simulation capabilities and features of various simulation languages. These tables state inherent features of each simulation language. Features include the presence or absence of animation, orientation, and statistical capabilities and more.

Many simulation models have been developed of materials handling systems. Material handling systems are often hard to model, simulation software developments must reflect this complexity [Conway & Maxwell, 1987]. Conway and Maxwell (1987) modelled asynchronous material handling in XCELL+. Sale and Stein (1987) modeled AGVS Systems using SLAM. Godziela (1986) modeled a flexible manufacturing cell with material handling via a crane. Litton Unit Handling System's simulation staff used GPSS/H to model order picking and conveyor sortation and other material handling ideas. Eaton-Kenway, a leader in the area of automated material handling systems, first began modeling material handling systems using GPSS now they use AutoSimulation's AutoMod simulation software. Cincinatti Milacron utilized SIMAN to model traditional transfer lines and automated manufacturing systems [1991, IE Magazine, author unknown]. The list goes on and on. Many have utilized simulation software to model material handling components.

Literature clearly states, there exists a problem in modeling automated material handling devices, but it never states all necessary requirements of a simulation package to properly model material handling systems.

Sturrock and Pegden (1990) state that material handling is an essential part of most manufacturing systems. Devices such as AGVS, robots, conveyors, etc. are "extremely difficult to model." Therefore it is necessary to state those attributes of various material handling devices which make it hard to model. Only then may we find complete solutions to this problem and determine what simulation software requirements are necessary for modeling these materials handling components.

Based on findings, no one has specifically addressed the issue of which software package is preferred for modeling material handling components. Papers have been written about the material handling constructs which a given system may contain, but no references were found which compare and contrast the material handling components of numerous systems. The following statement was made by John Carson (1990) in proceedings of an Autofact conference and is believed to be true about recent literature in the area of simulation languages and simulators.

"Many published reviews in the literature are shallow

> and superficial, in the sense that they consist of a check list of claimed generic features..." [John S. Carson, 1990]

In other words there has been very little in-depth comparisons of simulation languages and simulators in the past ten years.

2.4 SIMAN

SIMAN is a SIMulation ANalysis program for modeling various systems. It was developed by Dennis Pegden over eight years ago. Since its initial development, it has undergone reconstruction, as noted by the four versions of SIMAN. These enhancements were an effort to improve modeling features and maintainability of its code. The SIMAN simulation language has capabilities for modeling discrete, continuous and discrete-continuous systems. Its modeling capabilities are increased with the use of user-defined subroutines [Sturrock & Pegden, 1990].

Though SIMAN is a general-purpose simulation language, this paper only discusses its capabilities for modeling manufacturing systems. SIMAN is sometimes compared to manufacturing languages (XCELL and SIMFACTORY). It has been found that SIMAN provides greater modeling flexibility than manufacturing languages. Unlike SIMAN, most manufacturing languages are not applicable to a variety of manufacturing systems. On the other hand, as compared to other general-purpose simulation languages (SLAM), SIMAN provides features specifically for modeling manufacturing systems. It was developed in an effort to simplify the modeling of manufacturing systems [Sturrock and Pegden].

SIMAN was developed with constructs which should greatly reduce modeling difficulties and enhance modeling capabilities of material handling within a manufacturing system. For this reason, SIMAN is one of the simulation languages being researched in this document.

Recently, a CINEMA system was developed to be used with SIMAN. CINEMA allows real-time graphics animation. Thus, SIMAN is often referred to as SIMAN/CINEMA. This means of graphics animation is very effective in understanding and presenting the dynamics of the system being modeled.

2.5 GPSS

GPSS (General Purpose Simulation System) was first introduced in 1961 by Geoffrey Gordon of IBM Corporation. Since its introduction, it has undergone several evolutions. GPSS/H was developed in 1977 and was deemed faster than the original GPSS. It offers a real-time simulation clock, capabilities to read and write external files, tailored output reports, random number generation features, mathematical functions, and control statements. Due to these capabilities most systems modeled in GPSS do not require external routines [Law and Kelton, 1991].

Based on a recent study by Law and Haider (1989) GPSS/PC does not contain special materials handling constructs, neither does GPSS/H. It is still believed that GPSS is a good tool for modeling such complex systems, therefore, its ability to model materials handling systems is also analyzed.

This research focuses on the modeling capabilities of GPSS/H and GPSS/PC. The materials handling issues for either of these should be the same because GPSS/PC and GPSS/H have the same basic modeling elements [Law and Kelton, 1991].

2.6 SLAM II

SLAM II, the Simulation Language for Alternative Modeling, was the first simulation language to offer the capability of modeling a system using event, continuous, process, or any combination of the three. SLAM II has the ability to develop network-event-continuous models, thus making it a very flexible tool.

Since the introduction of SLAM by Dennis Pegden, in 1979, the simulation language has undergone several changes and additions. Pritsker & Associates are credited with refining and enhancing the software and developing it to the level which is known today as SLAM II. Various software systems have been developed to work in conjunction with SLAM II. TESS allows database management and capabilities for graphical model building, and animating model results. Recently, a Material Handling Extension (MHE) was introduced. MHE allows detailed modeling of material handling components: guidepaths, cranes, storage areas, and AGVS. SLAM II Interactive Execution Environment (IEE) allows the modeler to interrupt a simulation to examine or even change system parameters. Finally, SLAM II/PC Animation System allows graphical displays of models with its PC version [O'Reilly & Lilegdon, 1987]. The Material Handling Extension will be studied in-depth to determine its actual capabilities.

2.7 PROMODEL

PROMODEL (PROduction MODELer) is a simulation program designed for manufacturing systems. It combines the flexibility found in most simulation languages with the user-friendliness of manufacturing simulators to quickly model complex systems. Prior to the development of PROMODEL, simulation software was classified as either simulation languages or manufacturing simulators. Manufacturing simulators were not very flexible and simulation languages generally required programming. The developers of PROMODEL describe their product as a simulation "program", yet it is most often referred to by the general public as a manufacturing simulator. PROMODEL is designed for the simulation modeler with stringent time constraints and a desire to simulate a variety of production systems, therefore it attempts to combine ease of use and flexibility.

According to Law and Kelton (1991), PROMODEL is one of the most flexible manufacturing simulators on the market today. It has the ability to call C or Pascal routines to model complex systems. Its programming-like constructs provide flexibility, but do not reduce its ease of use. It also provides animation in character graphics.

PROMODEL uses the following basic modeling elements to allow its user to describe the system.

- Parts - items, entities, or production units which are processed in the system.
- Resources - machines, people, or devices which aid in processing the part.
- Routing - definition of part flow logic and move times.
- Operations - activities performed when the entity reaches a routing location.
- Part scheduling - the order, quantity, and frequency of entity creation.
- Resource capacities - maximum number of entities which can use the resource an a given time.
- Resource downtimes - built-in routines which model downtimes.
- User variables - counters, logic switches, etc. which aid in record keeping or decision making.
- Part Attributes - integer values assigned to a part to maintain identity.
- Function Tables - tables which allow the definition of sets of values (independent and dependent)
- Subroutines - user written routines which are

utilized when the complexity of the model exceeds the capabilities of ProModel's constructs.

- Time Entries - time values may be specified numerically, based on attributes, distributions, etc.
  [PROMODEL Corp., 1991]

ProModel also has built in material handling constructs. It has constructs which are believed to model transporters, cranes, robots, and conveyors with ease.

3.0 METHODOLOGY

3.1 OVERVIEW

There exists a vast array of AGVS, conveyors, cranes, etcetera. The purpose of this research is not to analyze all of the different types of material handling devices. This research focuses on only six specific types of material handling devices. For ease of understanding, each particular area (AGVS, conveyors, etc.) will be denoted as a separate class of material handling devices. It is necessary to define the actual type of material handling device within each class which was analyzed in this study. The following is a list of the automated and powered unit load materials handling devices which were analyzed. In many cases, these devices are referenced by their class which is in italics.

- Gantry *Cranes*
- Unit Load Carrier *AGVS*
- Automated Storage and Retrieval Systems (*AS/RS*)
- Industrial *Robots*
- *Industrial* Fork *Trucks* (Rider Trucks)
- Belt/Roller *Conveyors*

Though the operations of the various types of material handling devices within a given class are similar, it is still necessary to specify the particular type which is studied in this research. When defining the operating characteristics, one may find some features to be common among that particular class of material handling devices (i.e. bi-directional travel is a complexity which may be experienced by unit load carrier AGVS, forklift AGVS, towing vehicle AGVS, etc.). Thus, some issues which are relevant to the entire class of devices are addressed.

In order to achieve my objectives, it was important to determine the material handling features which should be addressed by simulation modeling prior to comparing the given simulation packages. Determining these materials handling features provided structure and data on which to base the comparison of simulation software packages.

First, a definition of each feature was generated for each material handling device. This list aided in the development of a survey which was completed by experts in each area of simulation software [SLAM, PROMODEL, SIMAN, and GPSS]. Valuable information was extracted from these surveys to assess the possible limitations and capabilities of each software package. Based on possible limitations and capabilities discovered, an assessment of the state-of-the-art in simulation software modeling of materials handling is stated.

3.2 Definition of Materials Handling Modeling Features

Material handling features are operative functions of materials handling devices which must be addressed when modeling using simulation. Each material handling device was analyzed separately to identify those features (i.e. speed, direction of movement, etc.) which must be defined to adequately model the system or device. To determine these features, the following approach was used.

1. A review of each material handling device was performed, to pinpoint complex material operating characteristics which must be modeled when using simulation.

2. Simulation programs which model the material handling devices were analyzed. Based on this analysis, parameters used to model material handling devices were extracted. These parameters were evaluated to determine modeling complexity of the materials handling device.

3. The list was given to experts in the area of simulation and material handling. Interviews were conducted with experts to determine whether the list was all encompassing. Feedback from experts served to verify the list previously generated.

Upon completion of the descriptive listing of materials handling modeling features, the results resembled the diagram in Figure 3.1.

3.3 Comparison of Software Packages

A review of the material handling modeling capabilities of each software package was performed. This review addressed issues, such as material handling modeling capabilities and special constructs designed to address materials handling issues for each software package.

Based on the features defined, a survey was developed and sent to experts of each software package under study. At least one expert was identified for each software package. The survey addresses each feature defined, as depicted in the schematic of the output in Figure 3.1. Experts were asked detailed questions about the capabilities of their software packages. A standard survey was sent to each expert. Based on responses, capabilities and possible limitations were displayed.

Information gathered allows the comparison of these software packages. Comparisons were based on capabilities and boundaries of the software packages. Based on capabilities, the state-of-the-art in simulation of materials handling capabilities was assessed. Opportunities for development are addressed for each software package.

The survey results and the definition of modeling features of material handling systems are all contributions to the body of knowledge.

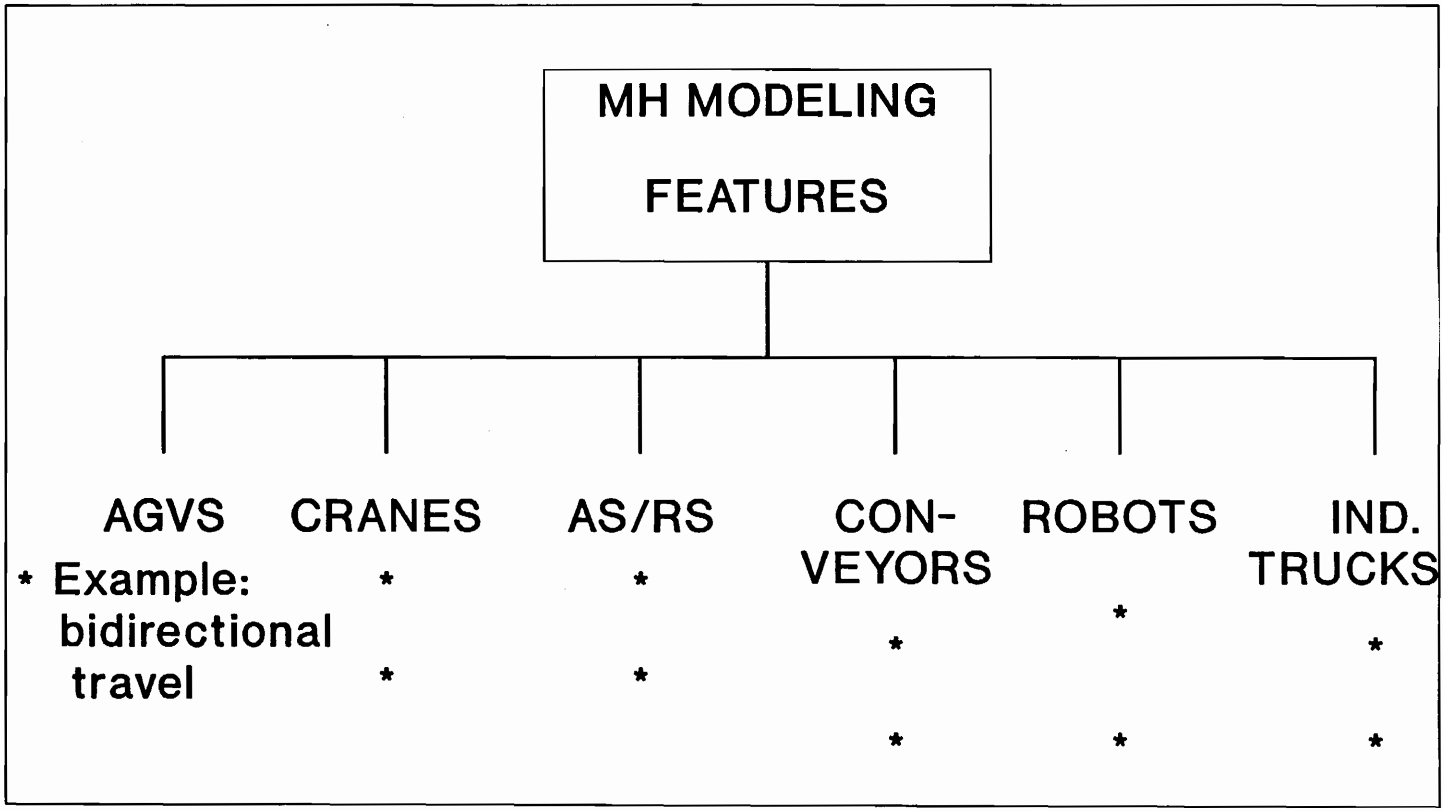

Fig. 3.1 Schematic diagram of output of defined features

4.0 Material Handling Attributes and Survey Design

4.1 Introduction

The following information details the design of this experiment. All information extracted from articles and simulation programs is displayed, as well as, procedures for survey development. All work which precedes the data analysis is specified in this chapter.

The analysis performed on each material handling device is discussed. By reading and interpreting material handling articles and simulation programs of each device, it was possible to extract those features which may be modeled when using simulation. These features are often referenced as attributes, model parameters, or characteristics. Inclusion of an attribute was determined by whether it could reflect the operating environment or management strategies of the device being simulated [Norman, 1984]. Based on knowledge of simulation, it was also helpful to consider whether an attribute could have an impact on elapsed simulated time or the simulation model building process overall. Thus, the list of simulation model parameters for material handling was developed. A sample survey which lists attributes and definitions is included in Appendix A.

A literature review was performed to aid in the development of the survey. Survey development and the resulting survey are later discussed.

The following sections detail each material handling device under study, material handling attributes which were revealed through research, survey development, and data collection procedures.

4.2 AGVS Analysis

The first wire-guided AGV system was developed in 1954 by A. M. Barrett, Jr. Since this time, the design of AGV systems has grown more complex, especially in the area of its control systems. Thus, modeling of modern AGV systems is also more complex. Through in-depth analysis of AGV literature and simulation programs. Some of the features which may be modeled when using simulation are presented below [Kulwiec, 1985].

For this study, the concept of automated guided vehicle systems implies a transport system which travels along a wire-guided path without driver assistance. Specifically, this research looks at unit load AGV systems. A schematic diagram of a typical AGV system is given in Figure 4.1.

The majority of the AGVS attributes were discovered through literary analysis. For purposes of discussion, all characteristics which were determined to be modeled for an AGVS may be divided into three categories:

1. Vehicle Attributes
2. Guidepath Attributes

3. Control System (Control Logic)

Vehicle attributes are those characteristics which involve modeling of the driverless vehicles in the AGV system. Guidepath attributes must also be considered when modeling AGV systems, due to the impact a layout can have on the operations of an AGV system. Finally, the control logic is an important aspect of material handling devices in simulation modeling. All attributes which fall within each category are discussed in detail in the following sections.

4.2.1 Vehicle Attributes

When specifying all necessary physical attributes which must be modeled to identify a specific vehicle, literature and simulation programs suggest the following situations. First, it is important to designate a home position for vehicles. The PROMODEL manual suggests a need to specify a point at which vehicles begin the simulation. Also, in reference to vehicle attributes, it is ofttimes necessary to designate a vehicle fleet which means that more than one AGV occupies the guidepath. By definition, characteristics of a fleet are homogenous, therefore, it is important to be able to specify characteristics for all vehicles in a fleet. Finally, there is the ability to have multiple fleets. Some industrial settings may incorporate the use of more than one type of vehicle. If this is the case, it is necessary to represent each class of vehicles through simulation

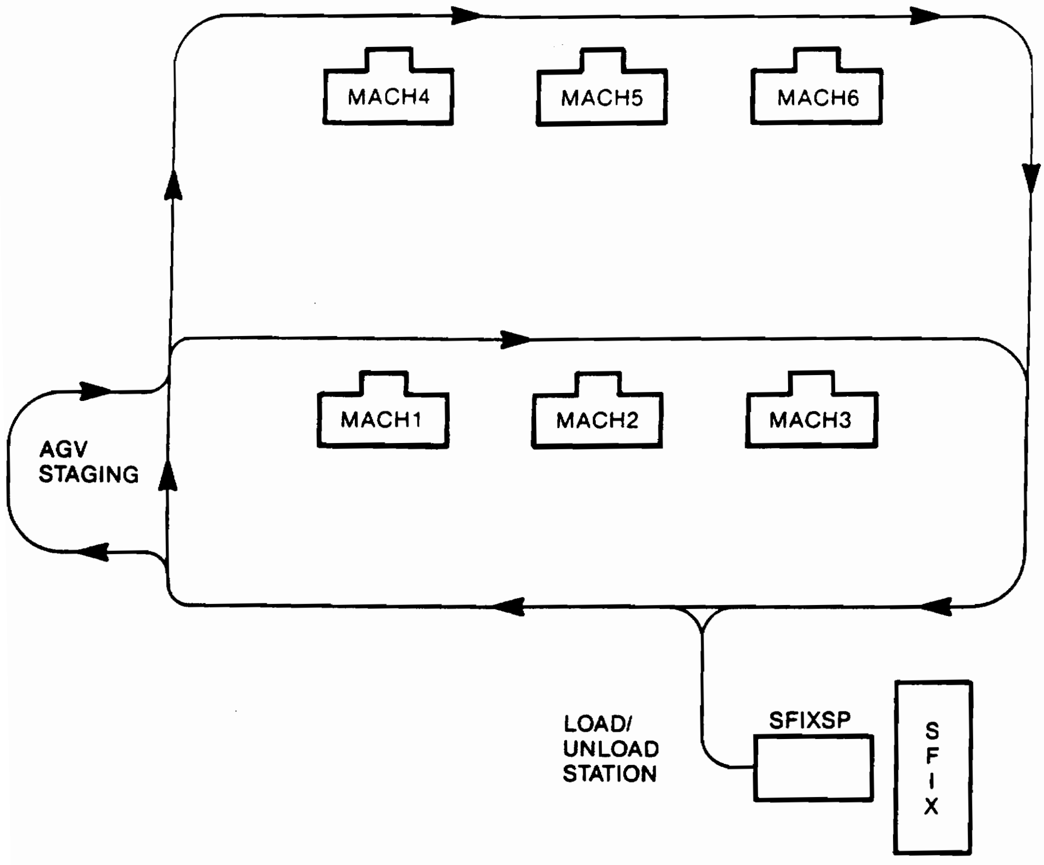

Figure 4.1 Schematic diagram of manufacturing cells with an AGVS (Reprinted from Reference [24].)

modeling. Some vehicles may be equipped for onboard operations. This must also be taken into consideration when including vehicle attributes in the simulation.

Functional characteristics of vehicles are also necessary to sufficiently model an AGVS. Functional characteristics are the operative properties of each vehicle. For instance, speed is an operative characteristic of a vehicle. Some simulation packages offer its user capabilities to specify the speed of a vehicle, while others require an input of travel time. Other operative characteristics which are important in simulation modeling are acceleration and deceleration. These characteristics may vary for a given vehicle depending on whether the vehicle is traveling empty or loaded, straight or curved. Pickup and deposit times are also desirable inputs for a simulation model of an AGVS. All of these model parameters may impact the operations of an AGV system.

4.2.2 Guidepath Attributes

Certain attributes of the guidepath must be considered when modeling an AGVS using simulation methods. It is first important to specify the layout of the guidepath. This requires the user of the simulation means to specify the entire path on which vehicles may travel. This may involve specification of distances to and from various points. A guidepath may resemble the outlined portion of Figure 4.1

which contains arrows to display direction of travel. Guidepaths may be more or less intricate than this diagram.

Some guidepaths are more detailed than others. Segments of a guidepath may be bi-directional. This implies that a vehicle may travel in more than one direction along the guidepath. Some guidepaths utilize spurs for loading, unloading, waiting, etcetera. Spurs are bi-directional segments which extend from the main guidepath. Only one vehicle is allowed to travel on the spur at a given time, because there is only one entry and exit point [Pritsker]. A guidepath may be broken into segments. One segment may experience a breakdown while all other segments are functional. Each segment may have limitations for the number of vehicles which may simultaneously travel on it at any point in time. There are various considerations when modeling the guidepath of an AGV system.

4.2.3 Control Logic

Conventional AGV systems require extensive control logic. Since each AGV has access to all workstations in the system, traffic management, vehicle routing, dispatching, and other control features are often complex to model [Bozer & Srinivasan]. Sale and Stein (1987) state that the control system is often the most difficult, yet most crucial, part of an AGVS model. In this research, the control system comprises the majority of the characteristics which were studied for AGV systems.

Traffic management is governed by the control logic of the AGVS. It is concerned with the routing of a vehicle, collision avoidance and all parameters which aid in these processes.

AGVs often have the ability to be routed over various routes along the guidepath. This is referred to as mapping. Many times it is desirable to route a vehicle over the shortest possible path, but sometimes it may be necessary to use an alternate route. If an AGV's path is blocked, it may be feasible to pass the blocking object or reroute its predetermined path of travel. It may also be necessary to redirect an in-transit vehicle when that vehicle is preempted. It may then be necessary to route a vehicle from its present location, without returning to a home position, to its next assignment. Depending on the system being modeled, routing may become very complicated.

Collision avoidance mechanisms are provided to avoid jams at various areas along the guidepath (i.e. at intersections, pickup/deposit points, and with other vehicles). In an effort to prohibit collisions, many AGV systems divide the entire system into zones. This is referred to as "zone blocking" [Bozer & Srinivasan] or zone control. The control system allows one vehicle in each zone at any given time. It would also be beneficial to collision avoidance if the simulation means incorporated a methodology which would allow each AGV to know the location, routing, load status, etcetera of other vehicles in the system. By knowing the parameter status of each vehicle, this would allow the AGV to take necessary actions to avoid collisions or route itself to its next destination.

Simulation modeling employs various priority rules associated with material handling situations for AGVS. Vehicle dispatching rules allow one to specify where to route a vehicle when multiple jobs await. Vehicle selection rules determine which vehicle will perform a given task when multiple vehicles are available. Some vehicle selection specifications may be nearest vehicle, least utilized vehicle, etcetera. Empty vehicle management rules may be necessary. These rules allow the user to specify routing locations when vehicles are idle. Priorities may also be specified at interface points. When two or more vehicles simultaneously reach an intersection, priorities will determine which vehicle may proceed. There is also the issue of job searching. Job search priorities specify which task to perform when multiple tasks await an AGV.

Other desirable model parameters include the ability to model battery recharging and maintenance (preventive and corrective). The ability to conveniently model an AGV which handles multiple loads or varying part types may be useful.

In reference to varying part types, the control system must be capable of retaining the identity of each part.

4.2.4 AGV Attributes Under Study

To recap those attributes whose ability to be modeled is desirable, the following list of attributes is given. This list comprises those attributes which were included in this study of AGVS.

1. Speed
2. Travel time
3. Pickup time
4. Deposit time
5. Home position
6. Acceleration
7. Deceleration
8. Empty Vehicle travel speed
9. Redirection of in-transit vehicles
10. Job search priorities
11. Mapping (excluding shortest route)
12. Shortest route mapping
13. Battery recharging
14. Guidepath layout
15. Spurs
16. Collision avoidance
17. Zone control
18. Control system
19. Vehicle fleet
20. Homogenous characteristics of a fleet
21. Multiple fleets
22. Vehicle limitations on guidepath
23. Onboard operations
24. Present location vehicle routing
25. Corrective maintenance
26. Preventive maintenance
27. Bi-directional travel
28. Passing
29. Rerouting
30. Path segment downtime
31. Vehicle dispatching
32. Vehicle selection
33. Empty vehicle management
34. Multiple Loads
35. Varying part types

36. Priorities at interface points
37. Parameter status

It is important to be able to specify these characteristics when using simulation to model material handling attributes of an AGVS. For a brief description of these attributes, please refer to the survey in Appendix A.

4.3 AS/RS Analysis

Automated storage and retrieval systems (AS/RS) are commonly found in manufacturing facilities today. The use of similar systems first began in Europe. The design of these systems developed from the desire to have more storage space without utilizing additional floor space. Therefore, developers utilized the vertical cube to create more storage areas. This, in effect, created problems in accessing the high storage locations. Eventually, a storage and retrieval (S/R) machine was created to access loads. This marked the beginning of the AS/RS as we know it today. [Kulwiec, 1985]

The storage racks and the S/R machine are the basic components of an AS/RS. Figures 4.2, 4.3 and 4.4 give a general pictorial of AS/R systems. To display the model parameters which were determined through research, the attributes are divided into three categories:

1. Rack considerations
2. Storage & retrieval control logic
3. S/R machine considerations

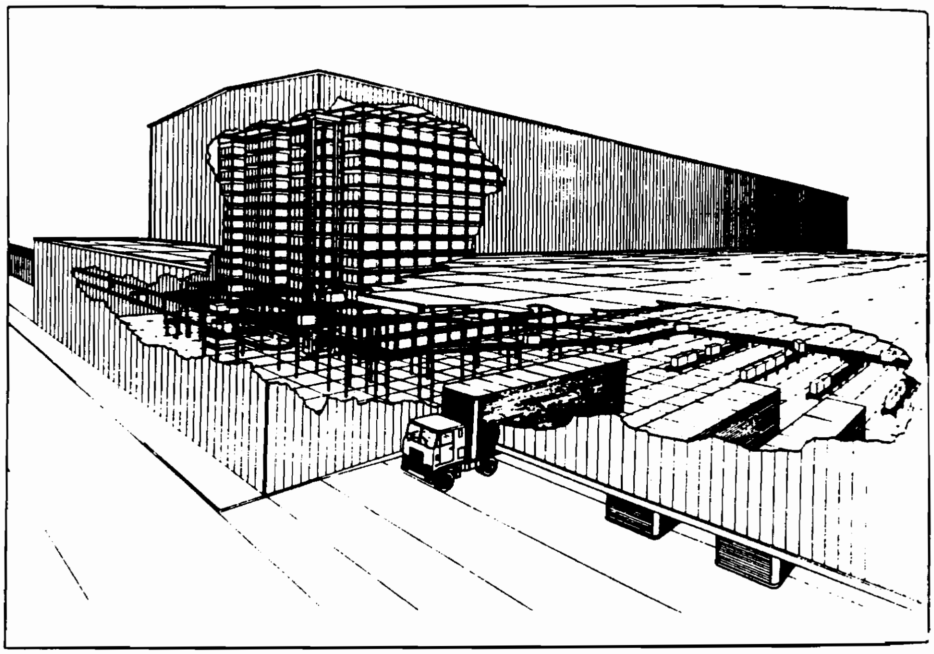

Figure 4.2 Rack supported building
(Reprinted from Reference [17])*

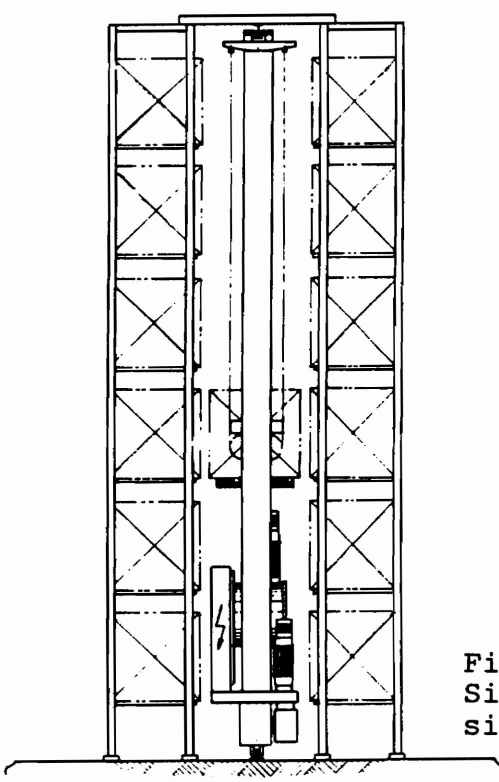

Figure 4.3
Single-wide aisle/
single-deep rack
(Reprinted from
Reference [17])*

* Ref. [17] reprinted
diagram from Ref. [7]

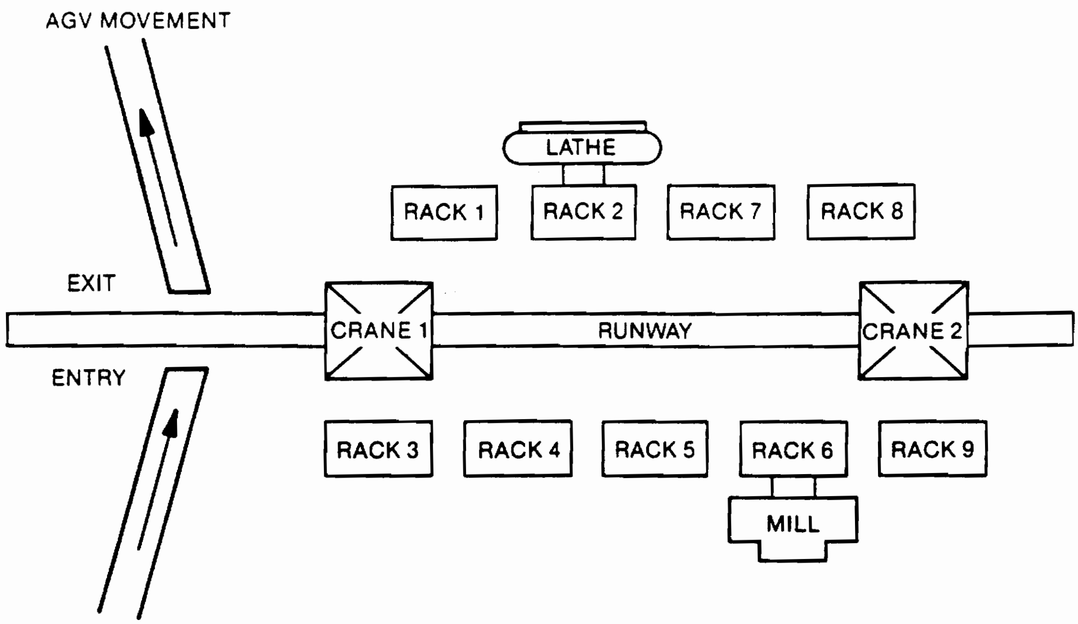

Figure 4.4 Schematic diagram of an AS/RS system (Reprinted from Reference [24])

4.3.1 Storage Rack Model Parameters

The storage racks are used to contain the unit loads. It is important when modeling to be able to specify storage rack configurations. It may be desirable to specify the number of rows and columns or the length of the aisles and the height of the racks. Storage racks are generally divided into individual storage locations or bins, which may also be modeled through simulation. Dimensions of individual storage locations is important. Given the size of a load, it may be necessary to determine which location is equipped to store the load, because storage dimensions and capacities may vary throughout an AS/RS. Often there are storage racks on both sides of an aisle, this too may be a desirable modeling input. Finally, an important concept which should be considered when designing simulation software for AS/RS, is zoning. Zoning is the partitioning of storage racks so different loads may be stored in designated areas [Caruso & Dessouky]. For instance, a certain section of the storage module may be used to store one type of load while another section is equipped to store loads with different specifications. Various situations must be addressed when modeling the storage racks of an AS/RS.

4.3.2 S/R Machine Model Parameters

When modeling the S/R machine, its movement capabilities must be addressed. First of all, it may be desirable to specify the hoisting (vertical) and cruising (horizontal) speed or travel time. Acceleration and deceleration capabilities must also be addressed when considering the speed of the S/R machine. These machines may move simultaneously in the horizontal and vertical directions when storing or retrieving a load. S/R machines must also travel to various input and output locations to deposit or retrieve a load.

Some S/R situations are relatively different from the basic AS/RS design. There may be multiple S/R machines on the same aisle. Each machine may be assigned a certain group of rows for storing and retrieving loads. Two aisles may share a common S/R machine, thus creating a need to model the transfer from one aisle to the other. Though uncommon, these situations must also be considered when developing simulation software to model AS/R systems.

4.3.3 AS/RS Control Logic

Finally, the control logic of an AS/RS must be considered. Simulationists may desire to model various storage and retrieval policies. Storage and retrieval policies are priority specifications for storing or retrieving loads. One may store based on the closest available bin, the closest available bin to its workstation, dedicated storage or a number of other specifications. Retrievals may be based on first in first out, last in last out, or other priority specifications.

There also exists dwell point strategies which allow the user of a simulation package to specify where to route the S/R machine when it is idle. The control logic for the AS/RS should also consider shuffle cycles which are sometimes necessary for double deep bins. This occurs when multiple unit loads are stored in a bin and the back load is desired. It may be necessary to remove and relocate the front load, in order to retrieve the back load. It could also be beneficial to simulationists if the software utilized could keep track of the present storage level. This would aid in determining reorder points.

An important issue discussed in a 1987 article written by Han, McGinnis, Shieh, and White, was the concept of retrieval sequencing. Two types of S/R machine cycles were discussed: single command and dual command. In single command retrieval sequencing, a single storage or retrieval is performed and the S/R machine returns to the I/O location. In dual command retrieval sequencing a storage and a retrieval are performed in the same cycle then the S/R machine returns to the I/O location. The control mechanism of an AS/RS must also be able to locate the part desired, schedule maintenance requirements, and handle dual shuttle storing capabilities. Various concepts concerning management strategies deserve consideration when discussing the control of the AS/RS.

4.3.4 AS/RS Attributes Under Study

The following is a list of attributes which will be studied to assess the AS/RS capabilities of various simulation software packages. For a brief description of each attribute, please refer to the appendix.

1. Storage rack configurations
2. Individual storage (bin) locations
3. Individual storage dimensions
4. Varying storage dimensions
5. Multiple loads
6. Capacity specifications
7. Shuffle cycles for double deep bins
8. Storage policies
9. Storage level determination
10. Storage racks on both sides
11. Retrieval policies
12. Part locating capabilities
13. Vertical speed (hoisting)
14. Horizontal speed (cruising)
15. Acceleration
16. Deceleration
17. Simultaneous horizontal and vertical travel
18. Varying input/Output (I/O) locations
19. I/O pick up
20. Storage pick up
21. I/O deposit
22. Storage deposit
23. Dwell point strategies
24. Single command retrieval sequencing
25. Dual command retrieval sequencing
26. Corrective maintenance
27. Preventive maintenance
28. Dual shuttles
29. Multiple S/R machines
30. Tier assigned S/R machines
31. Aisle transfer cars
32. Zoning

4.4 Belt/Roller Conveyor Analysis

The conveyor system is a popular material handling device for transporting and storing goods between production stages [Bastani, 1990]. Figures 4.5 and 4.6 depict typical conveyor systems. This study looks at issues surrounding simulation modeling of belt and live roller conveyors. It is believed that the modeling of the two systems share some commonalities.

Both belt and live roller conveyors are used to transport unit loads of various sizes. Belt conveyors are an economical means of transporting loads. The belt is often supported by rollers or a slider bed which may also be referred to as a metal bed. Loads are transported on the belt of the conveyor. Live roller conveyors are used for various applications. Accumulation may be performed using a live roller conveyor. Loads may be diverted on or off the conveyor using live rollers. Various types of drives (cable, chain, flat belt, etc.) are used to turn the rollers [Kulwiec, 1985].

4.4.1 Conveyor Layout

When modeling a conveyor system using simulation, the layout of the conveyor system must be considered. The conveyor geometry or the path taken must be considered. Oftentimes several conveyors are arranged to make the conveyor system. Literature states that "a conveyor system is a combination of one or more types of conveyors which interact to move parts" [PROMODEL Corp., 1991]. Therefore,

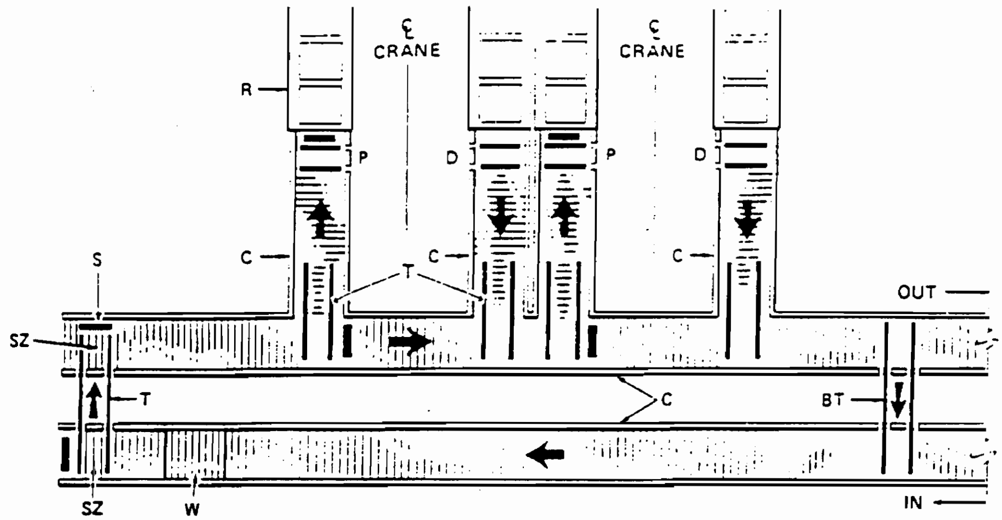

Fig. 4.5 Typical AS/RS front end conveyor. P = pickup station; D = deposit station; R = rack opening; S = squaring stop; W = weighing device; C = chain-driven live roller; T = two-strand chain transfer; BT = bypass transfer for missed or rejected loads; SZ = sizing stations.
(Reprinted from Reference [17])

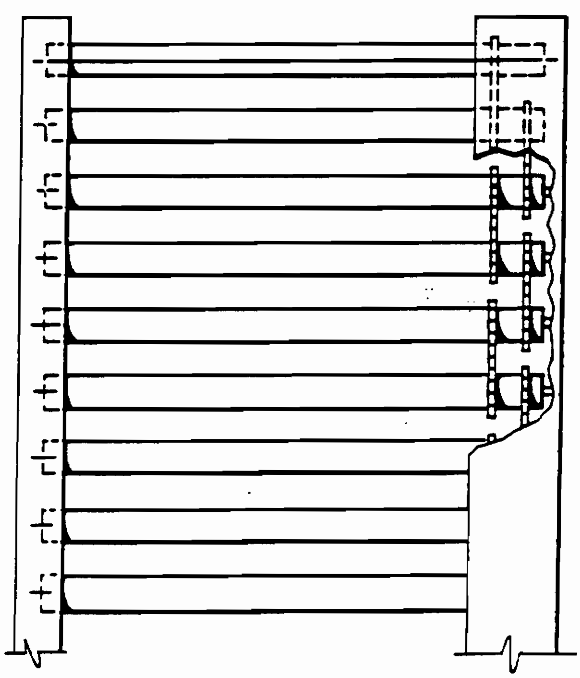

Figure 4.6
Chain driven live roller conveyor
(Reprinted from Reference [17])

some software packages break the conveyor system into sections which represent the various conveyors which make up the system. It may also be desirable to model the speed and the direction of travel for each conveyor. The conveyor system design is important to a simulation model.

4.4.2 Conveyor/Load Relationships

Simulation modelers must also consider the relationship between the conveyor and the transported load. Load dimensions may be important, especially when loads must be equally spaced on the conveyor. There is also the possibility that the loads transported may be of unequal dimensions. A simulation model may need to address these issues.

Various kinds of conveyors must be modeled. It is important for simulation software packages to have capabilities for modeling accumulation and transport conveyors. Accumulation conveyors allow loads to queue if forward movement is impeded [PROMODEL Corp., 1991]. Transport conveyors require loads to stop if movement of the leading load is prohibited [PROMODEL Corp., 1991]. There are also two way belt conveyors which consist of a bottom belt which also conveys.

Loading, unloading, and transferring of loads should also be considered. Loading and unloading time and location are possible model parameters. There may be simultaneous entries and exits occurring on a given conveyor. A conveyor may have multiple entry and exit points. Transfers may occur from one conveyor to another, off of a conveyor section, at a right angle and even bi-directional transfers are possible. Simulation software should address these issues.

In addition to the aforementioned parameters, sensing capabilities and maintenance should also be considered. Conveyor systems often utilize sensing capabilities for load management. It may be desirable to model the sortation of different part types based on the reading received from sensors. They may identify a defective part and route it accordingly. Preventive or scheduled maintenance may be modeled, as well as, corrective or unscheduled breakdowns.

4.4.3 Conveyor Attributes Under Study

Based upon information found, the following attributes were studied for the analysis of belt and roller conveyors.

1. Conveyor geometry
2. Direction of travel
3. Conveyor sections
4. Speed of sections
5. Load size
6. Spacing of loads
7. Sortation capabilities
8. Onboard operations
9. Transfer from sections
10. Transfer off conveyor
11. Right angle transfer
12. Loading time
13. Unloading time
14. Conveyor capacity
15. Bi-directional transfer
16. Two way belt conveyor

17. Loading/unloading points
18. Multiple entry/exit points
19. Simultaneous entries/exits
20. Accumulation
21. Transport
22. Loads with unequal lengths
23. Sensors
24. Preventive maintenance
25. Corrective maintenance

4.5 Gantry Crane Analysis

A basic gantry crane contains a runway, bridge, and hoist trolley. Figure 4.7 reflects the gantry crane structure. The bridge travels on the runway in what is known as the bridge direction [Pritsker, 1986]. The hoist trolley travels along the bridge. There is also a picking device, attached to the hoist trolley, which may be raised or lowered to allow one to load or unload a unit.

There are various possible types of crane systems. Multiple cranes may occupy one runway. Multiple cranes may occupy different bays. Cranes may also be equipped to handle multiple loads.

4.5.1 Crane Movement

When modeling the movement of a crane several issues must be mentioned. First, one must consider the movement of the bridge, hoist, and picking device. One may desire to specify speed, acceleration, and deceleration of each mobile part of the crane. The bridge and hoist movement is often simultaneous. One may want to specify the time required to pick up or deposit a load. Crane movement is important for

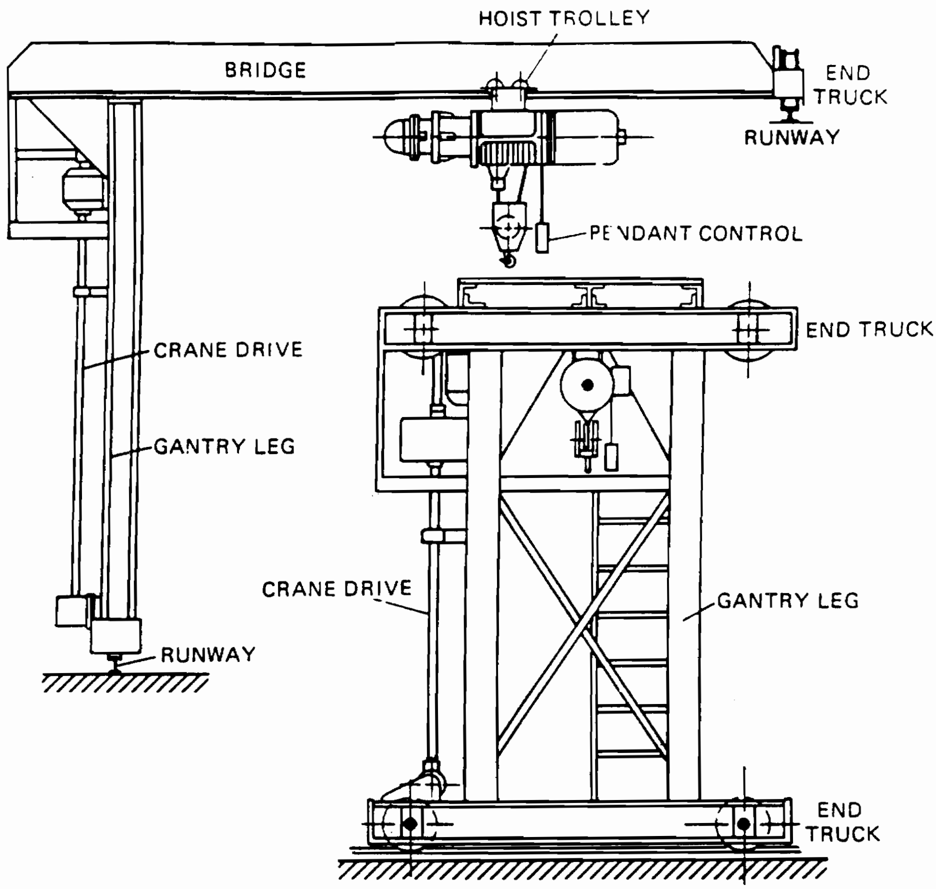

Figure 4.7 Gantry Cranes: single leg, top; double-leg, bottom (Reprinted from Reference [17])

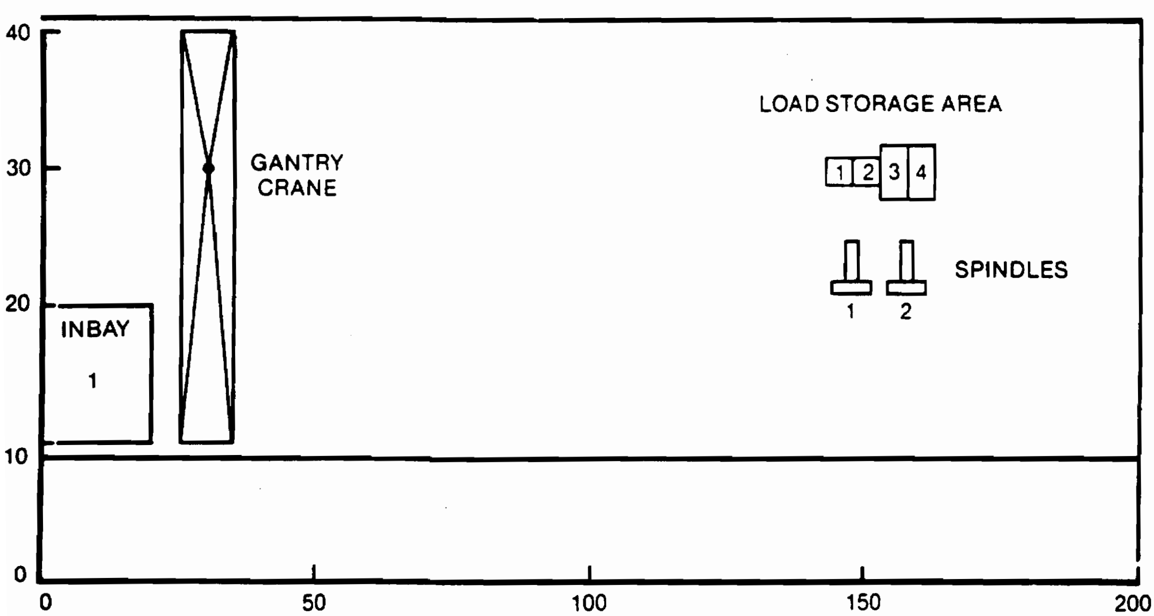

Figure 4.8 Schematic diagram of a crane transport operation (Reprinted from Reference [24])

proper simulation modeling of crane systems.

4.5.2 Crane System Priority Rules

Due to the fact that multiple cranes may share a common runway, interference is possible. Priority rules must determine which crane is allowed to continue to its destination while the other waits. There are also idle crane management rules which determine where to route a crane when it is idle. Job search priorities must be determined when multiple tasks await the same crane. Priority rules allow a more realistic model to be developed.

4.5.3 Position of Crane

Some means must be derived for locating the load which must be picked up or the area for deposit. It may be necessary to establish a reference point from which all other locations may be defined. Figure 4.8 shows a schematic diagram of a gantry crane with reference numbers also depicted. A frame of reference is needed to specify locations of travel.

4.5.4 Gantry Crane Attributes Under Study

The following attributes are studied throughout this research.

1. Bridge speed
2. Hoist speed
3. Picking device
4. Acceleration
5. Deceleration
6. Pick up time
7. Deposit time
8. Positioning
9. Job search priority

10. Simultaneous hoist and bridge movement
11. Multiple cranes on a runway
12. Multiple cranes in different bays
13. Interference
14. Idle crane management rules
15. Corrective maintenance
16. Transport of multiple loads

4.6 Industrial Fork Truck Analysis

The first forms of rider trucks began to receive widespread use after World War II. Since this time, the trucks have been redesigned to lift heavier loads, maneuver loads utilizing less floor space, and operate using electric power sources. Various other power sources are utilized, but for purposes of this research, we are analyzing those with electric motors. Because of their capabilities for rapid load movement, rider trucks are commonly used in materials handling and warehousing applications [Kulwiec, 1985].

A diagram of a typical industrial fork truck, which is analyzed in this study, may be found in Figure 4.9. When modeling this type of truck, some parameters may be based on control mechanics and maneuverability. To model the maneuverability, one must consider speed, acceleration, deceleration and possibly the time required to load and unload. One must also consider the movement of the forks. Forks may have various lift specifications. Varying lift specifications may have different time requirements. The control of an industrial fork truck includes specifications

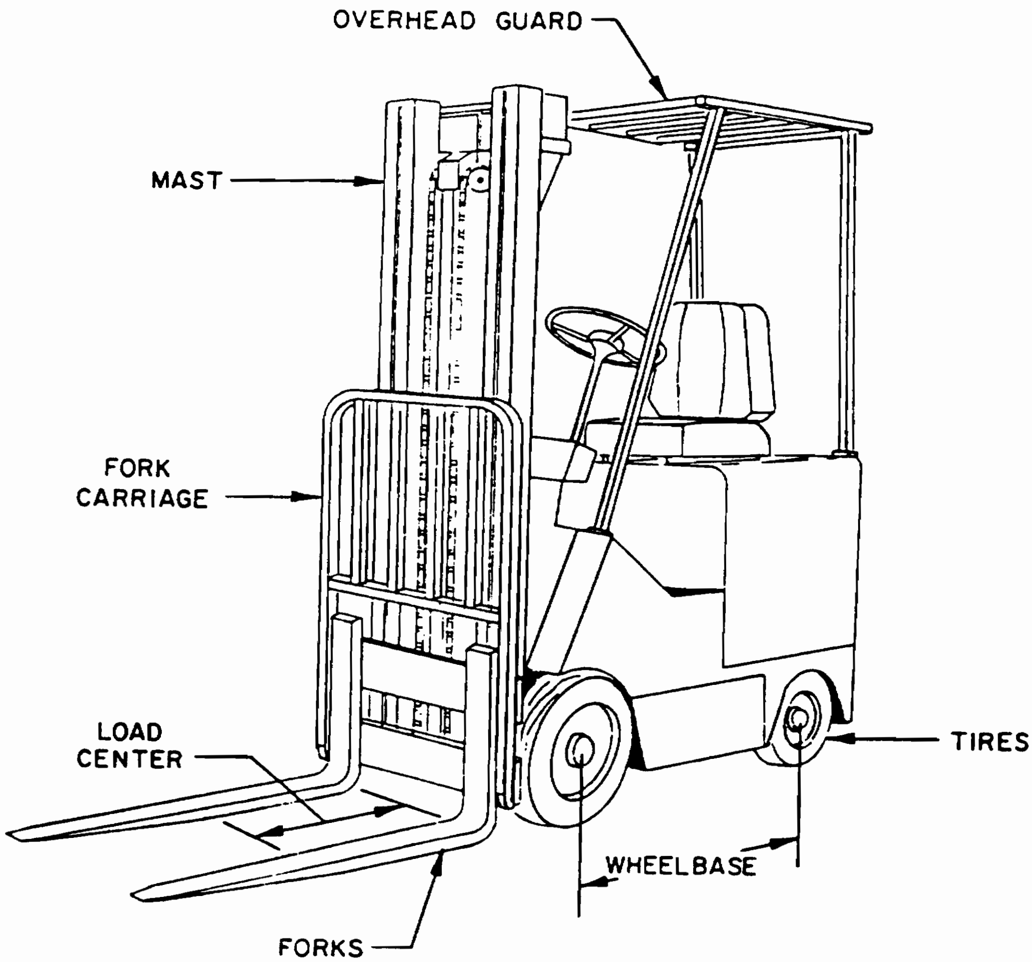

Figure 4.9 Typical fork truck construction (Reprinted from Reference [17])

for collision avoidance, battery recharging, routing and vehicle selection. Movement and control logic are important parameters when modeling industrial fork trucks.

4.6.1 Industrial Fork Truck Attributes Under Study

For purposes of this research the following attributes are considered important model parameters for simulation modeling of industrial fork trucks.

1. Speed
2. Travel time
3. Pick up time
4. Deposit time
5. Home position
6. Acceleration
7. Deceleration
8. Lift specifications
9. Job search priority
10. Battery recharging
11. Distance traveled
12. Varying speeds
13. Collision avoidance
14. Path specifications
15. Passing
16. Routing from present location
17. Vehicle selection
18. Corrective maintenance
19. Preventive maintenance
20. Load and fixture separation

4.7 Industrial Robot Analysis

The industrial robot is basically a flexible manipulator. Kulwiec's Materials Handling Handbook classifies industrial robots as a unit load material handling device. Schematic diagrams of industrial robots may be found in Figures 4.10 and 4.11. According to Kulwiec, the Robot Institute of America distinguishes robots

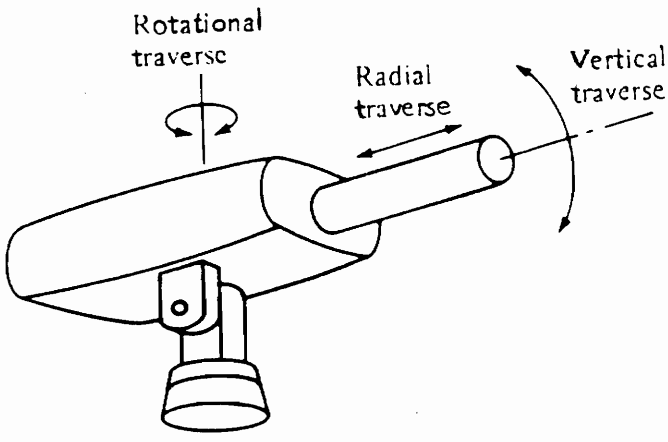

Figure 4.10 Degrees of freedom of a polar coordinate robot (Reprinted from Reference [15])

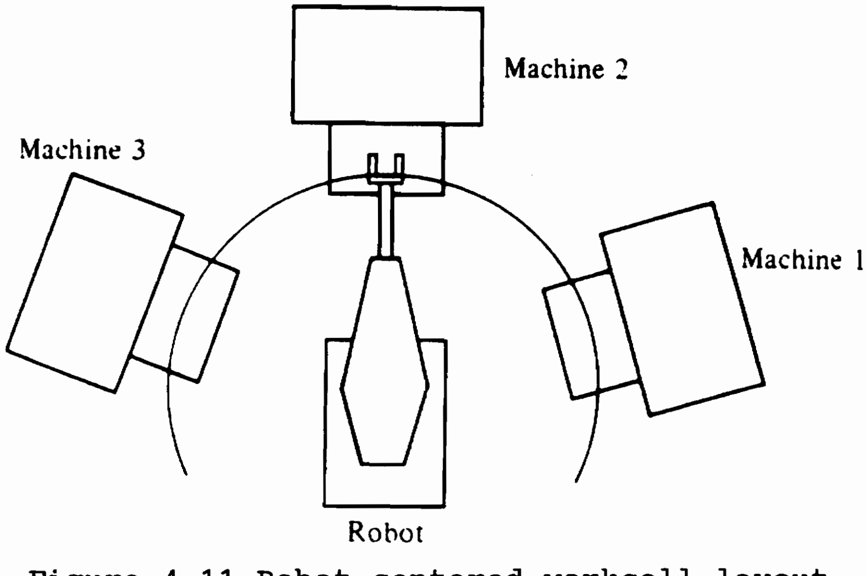

Figure 4.11 Robot-centered workcell layout (Reprinted from Reference [15])

as "reprogrammable, multi-functional manipulators designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks". Robots also include automation devices which allow it to perform a sequence of tasks which may be repetitious [Kulwiec, 1985].

Industrial robots may have as many as seven axes of motion. This study looks at robots which may traverse in vertical, radial, and rotational directions. Simulation modelers may desire to model movement in any or all of these directions.

Various considerations are relevant when modeling industrial robots by simulation methods. First, the path logic may be a desirable model parameter. It is important to model the path taken by the manipulator. Robots have the capability to perform various tasks at multiple service stations. Work envelopes may overlap when multiple robots are utilized. Therefore, consideration must be provided to avoid collisions.

Robots are not fail proof. Often when grasping an object, multiple attempts must be made to secure the object. Sensing capabilities may aid in locating the object which must be grasped. Sensors provide information which often determines the next move for the robot. Modeling of sensing capabilities may be beneficial to simulation modelers.

4.7.1 Industrial Robot Attributes Under Study

The following attributes will be used to asses the capabilities of simulation software packages to model industrial robots.

1. Home Position
2. Multiple degrees of freedom
3. Vertical traverse
4. Radial traverse
5. Rotational traverse
6. Travel time
7. Speed
8. Speed for all degrees of freedom
9. Path logic
10. Multiple tasks performed
11. Job search priorities
12. Sequence variation
13. Pick and place
14. Multiple grasping attempts
15. Sensors
16. Shared work envelopes
17. Multiple service stations
18. Corrective maintenance
19. Preventive maintenance

4.8 Questionnaire Development

A literature review on questionnaire development was performed, in an effort to produce the most effective survey possible. Various points were considered due to this literature review. Some of the issues which were addressed were preliminary considerations (i.e. question development and feedback on questions asked), use of closed or open ended responses, performance of pilot tests and the promotion of survey responses.

4.8.1 Preliminary Survey Considerations

According to Frary (1991), the first step in questionnaire development is to define the desired information. After determining the information desired, consult potential consumers of the results to receive feedback [Frary, 1991]. The earlier sections of this chapter presented all of the issues which are to be addressed by this survey. The lists of attributes were reviewed by simulation and material handling specialists to ensure that the lists were all encompassing. Minor changes were made by these specialists and those changes are included in the lists of attributes displayed in previous sections. After a review from specialists, the survey questions were developed.

First, it was desirable to know whether the given software package had the ability to model each attribute. If the software was capable of modeling the attribute, it was then necessary to know how it may be modeled. Three categories were developed to address this issue: direct, indirect, and external modeling methods. These categories will be discussed in detail in the following section. Finally, this survey seeks to determine the level of difficulty experienced when modeling each attribute of the material handling devices.

Survey respondents were identified and contacted. Respondents were all proficient in the use of one of the software packages under study. Backstrom and Hursh-Cesar

(1981) discuss what dictates sample size. In this literature it states that homogeneity of respondents affects sample size, therefore, if respondents' views are similar, few people are needed for a good sample. This survey was only completed by "experts" in their fields. It was expected that the panel of experts would possess similar opinions and therefore minimize the required sample size.

4.8.2 Question Form

Survey questions may be classified as closed-ended or open-ended. A closed-ended question requires a fixed response. It gives the respondent a choice of specific answers which are already provided in the survey. An open-ended question allows the respondent to compose their own answers. It is most desirable to develop surveys which are predominantly closed-ended [Backstrom & Hursh-Cesar, 1981]. Geer (1991) states that closed-ended questions are the overwhelming choice of most survey researchers, because, they are easier to ask, code, and analyze.

Open-ended questions are likely to suppress survey responses. Therefore, they should be avoided in most cases. One positive aspect of this type of question is it may capture unsuspected information. This is the reason many give for using this question format [Frary, 1991].

Based on the literature review performed, it was decided to develop a survey with closed-ended questions. An additional page was provided to allow respondents to elaborate if they deemed it necessary.

The first question, "Can the following material handling operations be modeled using this software package?", has two possible answers: yes or no. The second question seeks to determine the method which is used to model a given situation. The following are the possible responses.

> <u>direct</u> - special constructs/resources (e.g., a conveyor blocks) or general material handling constructs (e.g., transporters) are specially designed to model the material handling device and the specified operation.
>
> <u>indirect</u> - generic resource blocks or general modeling features are used to model the material handling operation.
>
> <u>external</u> - general purpose languages (FORTRAN, C, PASCAL, etc.) must be used to model the specified operation; one must employ user-written routines to model the given situation

The third question displays the difficulty one may experience when modeling the material handling situations under study. To reduce the subjectivity of this question, it was necessary to establish a frame of reference for responses. The level of difficulty required to model each characteristic of the material handling device was assessed in terms of time and/or lines of code required. The possible responses for this category were easy, moderate, and difficult.

4.8.3 Pilot Tests Performed

Upon completion of the first draft of the survey, a pilot test was performed. A group of possible survey participants were asked to complete the survey and critique its effectiveness. Interesting issues were brought to the forefront based on responses from the pilot test performed. Most comments were based on understanding the meaning of the structured responses. Their was not a concrete understanding of terms used: direct, indirect, external, easy, moderate, and difficult. Therefore, the definitions previously given were developed and a frame of reference was developed for the levels of difficulty. The survey also contains definitions for each material handling attribute under study. This helps to ensure that respondents understand the question asked.

The survey was also taken to the Test-scoring Office of Virginia Polytechnic Institute and State University for review and feedback. The Test Scoring Office specializes in survey development. Employees are proficient in the development of various types of surveys. Feedback received was positive. No changes were recommended.

4.8.4 The Resultant Survey

Based on literature and feedback from various sources, the survey displayed in Appendix A was developed and used to gather information for this research.

5.0 Data Analysis and Results

5.1 Survey Responses

Surveys were sent to colleagues and associates of committee members. This definitely increased the response rate. Approximately thirty surveys were given to experts in simulation modeling of manufacturing systems. The expected response rate was relatively high due to the fact that the surveys were sent to associates of committee members. Despite expectations, the response rate was less than fifty percent. Twelve surveys were returned within a three week period.

The only demographic data which was required of each respondent was the years of experience with the software under study. Table 5.1 displays the years of experience of each respondent for the four software packages under study.

Table 5.1: Years of experience for each respondent

GPSS	PROMODEL	SIMAN IV	SLAM II
3 years	<1 year	6 years	5 years
2 years	10 years	4-5 years	1.5 years
	1.5 years	10 years	10 years
		10 years	

5.2 Raw Data from Survey Responses

Responses for each attribute were put into a table format. For ease of data analysis and accuracy, Quattro Pro for Windows was utilized. Tables in Appendix B depict the responses which were given by survey respondents for each material handling device and each software package.

5.3 Analysis of Survey Responses

The first step in the analysis was to convert the raw data into percentages. This would give a clear view of the beliefs of the majority. The tables in Appendix B denote this step in the data analysis process.

Given the structure of the survey and the information desired, it was believed that most responses, for a given software package, would be the same. Variations in the level of difficulty were anticipated, because this area remains somewhat subjective. After viewing the percentage tables in Appendix B, it was realized that respondents did not agree on the capabilities of some attributes. Those issues where there was no consensus were identified. If there was no consensus, it was not feasible to draw conclusions. Drawing conclusions on these characteristics could result in a faulty data analysis.

All conclusions were drawn based on a common response of the majority. A threshold value was selected to represent the majority. After looking at the tables of percentages, it was decided that a minimum of 67% of the responses must agree to declare the capabilities of the software. Using this threshold value, data was summarized and results are displayed in Tables 5.2 through 5.7.

5.3.1 Understanding the Data Summary Tables

Tables 5.2 through 5.7 display the modeling capabilities, modeling method utilized, and the level of difficulty based on the majority of responses for each attribute. This table presents and compares the modeling abilities of each software package under study. Under the category for modeling capability, if the software is capable of modeling a given attribute, it is denoted with an "X". If the software is unable to model the characteristic it is denoted with a "0". If the software package is unable to model a given characteristic, following categories will be blank because there is no reason to answer the other questions if modeling is deemed impossible. The modeling method is handled in a similar fashion. If a characteristic is modeled directly it is denoted with an "X", indirectly "X-", and externally "0". When viewing the level of difficulty, "X" denotes the attribute is easy to model based on time and lines of code required to model. "X-" represents a moderate level of difficulty, and "0" denotes the attribute is hard to model using the given software.

Table 5.2: Data Summary for AGVS

SECTION A:		MOD. CAPABILITY X = Yes 0 = No NC = No Consensus				MODELING METHOD X = Direct X- = Indirect 0 = External NC = No Consensus				LVL. OF DIFFICULTY X = Easy X- = Moderate 0 = Difficult NC = No Consensus			
	AUTOMATED GUIDED VEHICLE SYSTEMS	GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM
1	SPEED	X	X	X	X	X-	X	X	X	NC	X	X	X
2	TRAVEL TIME	X	X	X	X	X	X	X	X	X	X	X	X
3	PICKUP TIME	X	X	X	X	X	X	NC	X-	X	X	X	X
4	DEPOSIT TIME	X	X	X	X	X	X	NC	X	X	X	X	X
5	HOME POSITION	X	X	X	X	X-	X	X	X	NC	X	X	X
6	ACCELERATION	NC	X	X	X	NC	X	X	X	NC	X	X	X
7	DECELERATION	NC	X	X	X	NC	NC	X	X	NC	X	X	X
8	EMPTY VEHICLE TRAVEL SPEED	X	NC	X	X	X-	NC	X	X	NC	NC	X	X
9	REDIRECTION OF IN-TRANSIT VEHICLES	X	0	X	X	X	X-	NC	NC	X	X-	X-	NC
10	JOB SEARCH PRIORITIES	X	X	X	X	X	X	NC	X	X	NC	X	X
11	MAPPING (excluding shortest route)	X	X	X	X	X	X	X	0	X	NC	X	X-
12	SHORTEST ROUTE MAPPING	X	X	X	X	X	NC	X	X	X	NC	X	X
13	BATTERY RECHARGING	X	X	X	X	X	X-	X-	NC	X	X	X	X-
14	GUIDEPATH LAYOUT	X	X	X	X	NC	X	X	X	NC	NC	NC	X
15	SPURS	NC	X	X	X	NC	NC	X	X	NC	NC	X	X
16	COLLISION AVOIDANCE	X	X	X	X	X-	NC	X	X	0	NC	X	X
17	ZONE CONTROL	X	X	X	X	X-	X	X	NC	NC	NC	X	NC
18	CONTROL SYSTEM	X	X	X	X	X-	NC	X-	0	0	NC	NC	X-
19	VEHICLE FLEET	X	X	X	X	X	X	X	X	X	X	X	X
20	HOMOGENOUS CHARACTERISTICS OF FLEET	NC	X	X	X	NC	X	X	X	NC	X	X	X
21	MULTIPLE FLEETS	NC	X	X	X	NC	X	X	X	NC	X	X	X
22	VEHICLE LIMITATIONS ON GUIDEPATH	X	X	X	X	NC	NC	X	X	X	NC	X	X
23	ONBOARD OPERATIONS	X	X	X	X	X	NC	NC	X-	X	NC	NC	X
24	PRESENT LOCATION VEHICLE ROUTING	X	NC	X	X	X-	NC	X	X	0	NC	X	X-
25	CORRECTIVE MAINTENANCE	X	X	X	X	X	X	X-	NC	NC	X	NC	X
26	PREVENTIVE MAINTENANCE	X	X	X	X	X	X	NC	X-	X	X	X	X
27	BI-DIRECTIONAL TRAVEL	NC	X	X	X	NC	X	X	X	NC	X	NC	X
28	PASSING	NC	NC	X	X	NC	NC	NC	0	NC	NC	X-	X-
29	REROUTING	X	X	X	X	NC	X-	X-	0	X-	NC	X-	X-
30	PATH SEGMENT DOWNTIME	X	X	NC	X	X	X-	NC	0	X	NC	NC	X-
31	VEHICLE DISPATCHING RULES	X	X	X	X	NC	X	X	X	NC	X	X	X
32	VEHICLE SELECTION	NC	X	X	X	NC	NC	X	X	NC	NC	X	X
33	EMPTY VEHICLE MANAGEMENT	X	X	X	X	NC	NC	X-	X	NC	NC	X-	X
34	MULTIPLE LOADS	X	NC	X	X	NC	NC	X-	NC	X	NC	X-	NC
35	VARYING PART TYPES	X	X	X	X	X	NC	X-	X	X	NC	X	X
36	PRIORITIES AT INTERFACE POINTS	NC	X	X	X	NC	X-	X	X	NC	X-	X	X
37	PARAMETER STATUS	NC	NC	X	X	NC	NC	X	X-	NC	NC	X-	NC

Table 5.3: Data Summary for AS/RS

SECTION B:		MODELING CAPABILITY				MODELING METHOD				LEVEL OF DIFFICULTY			
		X = Yes 0 = No NC = No Consensus				X = Direct X- = Indirect 0 = External NC = No Consensus				X = Easy X- = Moderate 0 = Difficult NC = No Consensus			
	AUTOMATED STORAGE/RETRIEVAL SYSTEMS	GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM
1	STORAGE RACK CONFIGURATION	X	X	X	X	NC	X-	NC	X	NC	NC	NC	X
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	X	X	X	X	X	X-	X-	X	X	NC	NC	X
3	INDIVIDUAL STORAGE DIMENSIONS	X	NC	X	X	NC	NC	X-	NC	NC	NC	X-	NC
4	VARYING STORAGE DIMENSIONS	X	X	X	X	NC	NC	X-	NC	NC	NC	X-	NC
5	MULTIPLE LOADS	X	X	X	X	X-	X	NC	NC	NC	X	NC	NC
6	CAPACITY SPECIFICATION	X	X	X	X	NC	X	NC	X	NC	X	NC	X
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	NC	X	X	X	NC	X-	NC	X-	NC	NC	NC	X-
8	STORAGE POLICIES	NC	X	X	X	NC	X-	NC	NC	NC	NC	NC	NC
9	STORAGE LEVEL DETERMINATION	X	X	X	X	X-	NC	NC	NC	NC	NC	NC	X-
10	STORAGE RACKS ON BOTH SIDES	X	X	X	X	X-	NC	X-	NC	NC	NC	NC	NC
11	RETRIEVAL POLICIES	NC	X	X	X	NC	NC	X-	NC	NC	NC	X-	NC
12	PART LOCATING CAPABILITIES	X	X	X	X	X-	NC	NC	NC	NC	NC	NC	NC
13	VERTICAL SPEED (hoisting)	X	NC	X	X	X-	NC	NC	X	X-	NC	X	X
14	HORIZONTAL SPEED (cruising)	X	X	X	X	X-	X	NC	X	NC	X	X	X
15	ACCELERATION	NC	X	X	X	NC	X	X-	X	NC	X	X-	X
16	DECELERATION	NC	X	X	X	NC	X	X-	X	NC	X	X-	X
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	NC	NC	X	X	NC	NC	NC	X	NC	NC	X-	X
18	VARYING INPUT/OUTPUT LOCATIONS	X	X	X	X	X-	NC	NC	X	X	NC	NC	X
19	INPUT/OUTPUT PICK UP	X	X	X	X	X	X	X-	X-	X	X	NC	X
20	STORAGE PICK UP	X	X	X	X	X	X	X-	X-	X	X	NC	X
21	INPUT/OUTPUT DEPOSIT	X	X	X	X	X	X	X-	X-	X	X	NC	X
22	STORAGE DEPOSIT	X	X	X	X	X	X	X-	X-	X	X	NC	X
23	DWELL POINT STRATEGIES	X	X	X	NC	X-	X	X-	NC	0	X	NC	NC
24	SINGLE COMMAND RETRIEVAL SEQUENCING	X	X	X	X	X-	X	X-	NC	X	X	X-	NC
25	DUAL COMMAND RETRIEVAL SEQUENCING	X	X	X	X	X-	X	X-	NC	NC	X	X-	NC
26	CORRECTIVE MAINTENANCE	X	X	X	NC	X	X	X-	NC	NC	X	NC	NC
27	PREVENTIVE MAINTENANCE	X	X	X	X	X	X	X-	NC	X	X	NC	NC
28	DUAL SHUTTLES	X	NC	X	0	X-	NC	X-		NC	NC	NC	
29	MULTIPLE S/R MACHINES	NC	X	X	X	NC	X	X-	X	NC	X	X-	X
30	TIER ASSIGNED S/R MACHINES	X	X	X	X	NC	X-	X-	X	NC	NC	NC	X
31	AISLE TRANSFER CAR	X	X	X	NC	X-	X-	X-	NC	NC	NC	NC	NC
32	ZONING	X	X	X	X	X-	X-	NC	X	NC	X-	NC	X

Table 5.4: Data Summary for Conveyors

SECTION C: BELT/ROLLER CONVEYORS		MODELING CAPABILITY X = Yes 0 = No NC = No Consensus				MODELING METHOD X = Direct X- = Indirect 0 = External NC = No Consensus				LEVEL OF DIFFICULTY X = Easy X- = Moderate 0 = Difficult NC = No Consensus			
		GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM
1	CONVEYOR GEOMETRY	X	X	X	X	X	X	X	X-	X	X	NC	X
2	DIRECTION OF TRAVEL	X	X	X	X	X	X	X	X-	X	X	NC	X
3	CONVEYOR SECTIONS	X	X	X	X	X	X	X	X-	NC	X	NC	X
4	SPEED OF SECTIONS	X	X	X	X	X-	X	X	X-	NC	X	NC	X
5	LOAD SIZE	X	X	X	X	X-	X	X	NC	NC	X	NC	X
6	SPACING OF LOADS	NC	X	X	X	NC	X	X	NC	NC	X	NC	X
7	SORTATION CAPABILITIES	X	X	X	X	X	NC	NC	NC	X	NC	NC	X
8	ONBOARD OPERATIONS	NC	X	X	X	NC	X	X-	NC	NC	X-	NC	NC
9	TRANSFER FROM SECTIONS	X	X	X	X	X	X	X-	X-	X	X	NC	X
10	TRANSFER OFF CONVEYOR	X	X	X	X	X	X	X-	X-	X	X	NC	X
11	RIGHT ANGLE TRANSFER	X	X	X	X	X	NC	X-	X-	X	X	NC	X
12	LOADING TIME	X	X	X	X	X	X	X-	X-	X	X	NC	X
13	UNLOADING TIME	X	X	X	X	X	X	X-	X-	X	X	NC	X
14	CONVEYOR CAPACITY	X	X	X	X	X	X-	X	X-	NC	X	NC	X
15	BI-DIRECTIONAL TRANSFER	X	X	NC	X	X-	X	NC	X-	X-	NC	NC	X-
16	TWO WAY BELT CONVEYOR	X	X	X	X	NC	X-	NC	X-	X-	X-	NC	X-
17	LOADING/UNLOADING POINTS	X	X	X	X	X	X	X	X-	NC	X	NC	X
18	MULTIPLE ENTRY/EXIT POINTS	X	X	X	X	X	NC	X	X-	NC	X	NC	X
19	SIMULTANEOUS ENTRIES/EXITS	X	X	X	X	X	NC	NC	X-	NC	NC	NC	X
20	ACCUMULATION	X	X	X	X	X	X	X	X-	X	X	X	X
21	TRANSPORT	NC	X	X	X	NC	X	X	X-	NC	X	NC	X-
22	LOADS WITH UNEQUAL LENGTHS	X	X	X	X	X-	NC	X	X-	NC	NC	NC	NC
23	SENSORS	X	X	X	X	X	X	X-	X-	X	X	NC	X
24	PREVENTIVE MAINTENANCE	X	X	X	X	X	X	X-	X-	NC	X	NC	X
25	CORRECTIVE MAINTENANCE	X	X	X	X	X	X	X-	X-	X	X	NC	X

Table 5.5: Data Summary for Cranes

	SECTION D: GANTRY CRANES	MODELING CAPABILIT X = Yes 0 = No NC = No Consensus				MODELING METHOD X = Direct X- = Indirect 0 = External NC = No Consensus				LEVEL OF DIFFICULTY X = Easy X- = Moderate 0 = Difficult NC = No Consensus			
		GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM
1	BRIDGE SPEED	X	X	X	X	X-	X	X	X	NC	X	X	X
2	HOIST SPEED	X	X	X	X	X-	X	X-	X	NC	X	X	X
3	PICKING DEVICE	NC	NC	X	X	NC	NC	X-	X-	NC	NC	X	X
4	ACCELERATION (bridge & hoist)	NC	X	X	X	NC	X	X-	X	NC	X	X-	X
5	DECELERATION (bridge & hoist)	NC	X	X	X	NC	X	X-	X	NC	X	X-	X
6	PICK UP TIME	X	X	X	X	X	X	X-	X-	X	X	X	X
7	DEPOSIT TIME	X	X	X	X	X	X	X-	X-	X	X	X	X
8	POSITIONING	NC	X	X	X	NC	X	X-	X	NC	X	X	X
9	JOB SEARCH PRIORITY	X	X	X	X	X	X	X-	X	X	X	X	X
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	X	X	X	X	X-	NC	X-	X	NC	NC	X-	X
11	MULTIPLE CRANES ON RUNWAY	X	X	X	X	NC	X	X-	X	NC	NC	X-	X
12	MULTIPLE CRANES IN DIFFERENT BAYS	X	X	X	X	X	X	X-	X	NC	NC	X	X
13	INTERFERENCE	X	X	X	X	X-	NC	X-	X	NC	NC	NC	X
14	IDLE CRANE MANAGEMENT RULES	X	X	X	X	NC	X	X-	NC	NC	X	X-	NC
15	CORRECTIVE MAINTENANCE	X	X	X	X	X	X	X-	NC	NC	X	X-	NC
16	PREVENTIVE MAINTENANCE	X	X	X	X	X	X	X-	X-	X	X	X-	X
17	TRANSPORT OF MULTIPLE LOADS	X	NC	X	0	X-	NC	X-		NC	NC	X-	

Table 5.6: Data Summary for Fork Trucks

SECTION E: INDUSTRIAL FORK TRUCKS		MODELING CAPABILITY X = Yes 0 = No NC = No Consensus				MODELING METHOD X = Direct X- = Indirect 0 = External NC = No Consensus				LEVEL OF DIFFICULTY X = Easy X- = Moderate 0 = Difficult NC = No Consensus			
		GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM
1	SPEED	X	X	X	X	X-	X	X	X-	NC	X	X	X
2	TRAVEL TIME	X	X	X	X	X	X	X	X-	X	X	X	X
3	PICK UP TIME	X	X	X	X	X	X	NC	X-	X	X	X	X
4	DEPOSIT TIME	X	X	X	X	X	X	NC	X-	X	X	X	X
5	HOME POSITION	X	X	X	X	X	X	X-	NC	X	X	NC	X
6	ACCELERATION	NC	X	X	0	NC	X	NC		NC	X	NC	
7	DECELERATION	NC	X	X	0	NC	X	NC		NC	X	NC	
8	LIFT SPECIFICATIONS	X	X	X	NC	NC	X-	X-	NC	NC	0	X-	NC
9	JOB SEARCH PRIORITY	X	X	X	X	X	X	NC	X-	NC	X	X	X
10	BATTERY RECHARGING	X	X	X	X	NC	X-	X-	X-	X	X-	NC	X-
11	DISTANCE/TIME TRAVELED	X	X	X	X	NC	X	X	NC	X	X	X	X
12	VARYING SPEEDS	X	NC	X	X	X-	NC	X	NC	NC	NC	X	X
13	COLLISION AVOIDANCE	X	X	NC	X	X-	NC	NC	NC	0	NC	NC	NC
14	PATH	NC	X	X	X	NC	X	NC	NC	NC	X	NC	X-
15	PASSING	NC	NC	NC	X	NC	NC	NC	NC	NC	NC	NC	X-
16	ROUTING FROM PRESENT LOCATION	NC	X	X	X	NC	X-	X	NC	NC	X-	X	X-
17	VEHICLE SELECTION	NC	X	X	X	NC	X-	X	X-	NC	X-	X	X
18	CORRECTIVE MAINTENANCE	X	X	X	X	X	X	X-	X-	NC	X	X-	X
19	PREVENTIVE MAINTENANCE	X	X	X	X	X	X	X-	X-	X	X	X-	X
20	LOAD AND FIXTURE SEPARATION	X	X	X	X	X	X-	X-	X-	X	X-	NC	X-

Table 5.7: Data Summary for Industrial Robots

SECTION F: INDUSTRIAL ROBOTS		MODELING CAPABILITY X = Yes 0 = No NC = No Consensus				MODELING METHOD X = Direct X- = Indirect 0 = External NC = No Consensus				LEVEL OF DIFFICULTY X = Easy X- = Moderate 0 = Difficult NC = No Consensus			
		GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM	GPSS	PROMODEL	SIMAN	SLAM
1	HOME POSITION	X	X	NC	X	X	X	NC	X-	X	X	NC	NC
2	MULTIPLE DEGREES OF FREEDOM	X	NC	NC	X	X-	NC	NC	NC	X-	NC	NC	NC
3	VERTICAL TRAVERSE	X	NC	NC	X	X-	NC	NC	NC	X	NC	NC	NC
4	RADIAL TRAVERSE	X	NC	NC	X	X-	NC	NC	NC	X	NC	NC	NC
5	ROTATIONAL TRAVERSE	X	X	NC	X	X-	X	NC	NC	X	X	NC	NC
6	TRAVEL TIME	X	X	X	X	X-	X	X-	X-	X	X	NC	NC
7	SPEED	X	X	X	X	X-	X	NC	X-	X	X	X	NC
8	SPEED FOR ALL DEGREES OF FREEDOM	X	0	NC	X	X-		NC	NC	X		NC	X-
9	PATH LOGIC	X	X	NC	X	X-	X	NC	NC	X-	NC	NC	NC
10	MULTIPLE TASKS PERFORMED	X	NC	X	X	X-	NC	NC	NC	X-	NC	NC	NC
11	JOB SEARCH PRIORITIES	X	X	X	X	X	NC	X-	NC	X	NC	X	NC
12	SEQUENCE VARIATION	X	X	X	X	X-	X-	X-	X-	X-	X-	X	X-
13	PICK AND PLACE	X	X	X	X	X-	X	X-	NC	X	NC	X	NC
14	MULTIPLE GRASPING ATTEMPTS	X	NC	X	X	X-	NC	X-	NC	X	NC	X-	X-
15	SENSORS	X	X	X	X	X-	X-	X-	X-	X-	X-	NC	NC
16	SHARED WORK ENVELOPE	X	NC	NC	X	X-	NC	NC	X-	0	NC	NC	NC
17	MULTIPLE SERVICE STATIONS	X	X	X	X	X-	X	X-	X-	X-	X-	NC	NC
18	CORRECTIVE MAINTENANCE	X	X	X	X	X	X	X-	X-	X	X	X-	X
19	PREVENTIVE MAINTENANCE	X	X	X	X	X	X	X-	X-	X	X	X-	X

Finally, if there is no consensus for either category it is denoted with an "NC".

5.3.2 GPSS Material Handling Modeling Capabilities

Using Tables 5.2 through 5.7, one may see those attributes which GPSS has capabilities to model for each material handling device. Based on survey responses there are no known areas which GPSS cannot model.

The following conclusions are drawn using the histogram in Figure 5.1. According to this figure, GPSS directly models over half of the attributes studied for conveyors. It directly models virtually half of the AGV, and fork truck attributes under study. The vast majority of industrial robot characteristics are modeled indirectly, but it is noted that only one person responded to the industrial robot section of the survey. Therefore, a sound conclusion is not made for the modeling of industrial robots using GPSS. Approximately 40% (13 of the 32 attributes under study) of AS/RS attributes are modeled indirectly.

For a detailed look at the level of difficulty experienced when modeling each material handling device, please refer to the histograms in Appendix D. Viewing the pie chart in Figure 5.2, shows that overall, nearly 40% (58/150 total attributes under study) of the total characteristics analyzed were deemed easy to model. Only 6 attributes were identified as difficult to model by the

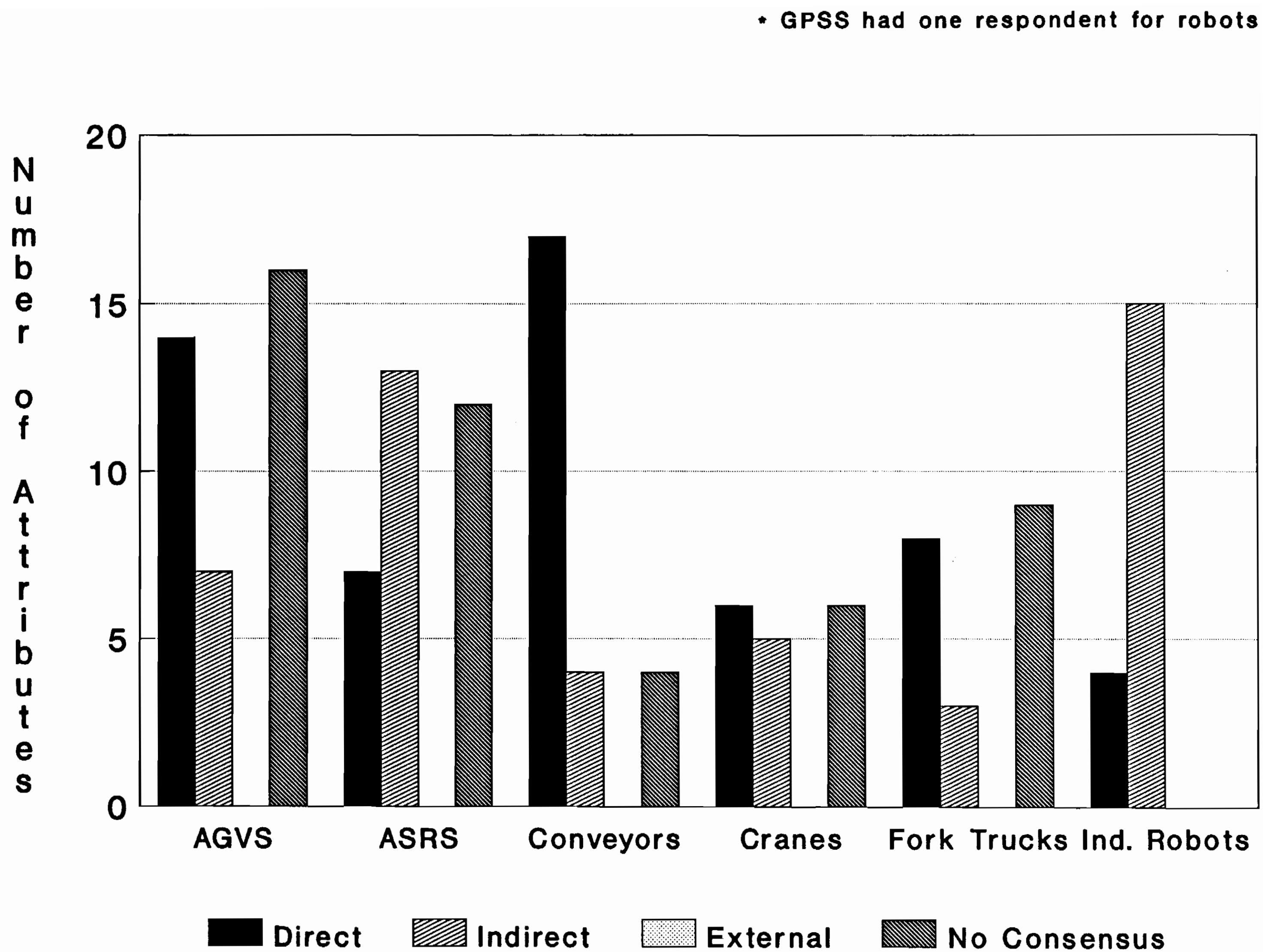

Figure 5.1: Modeling Methods for GPSS

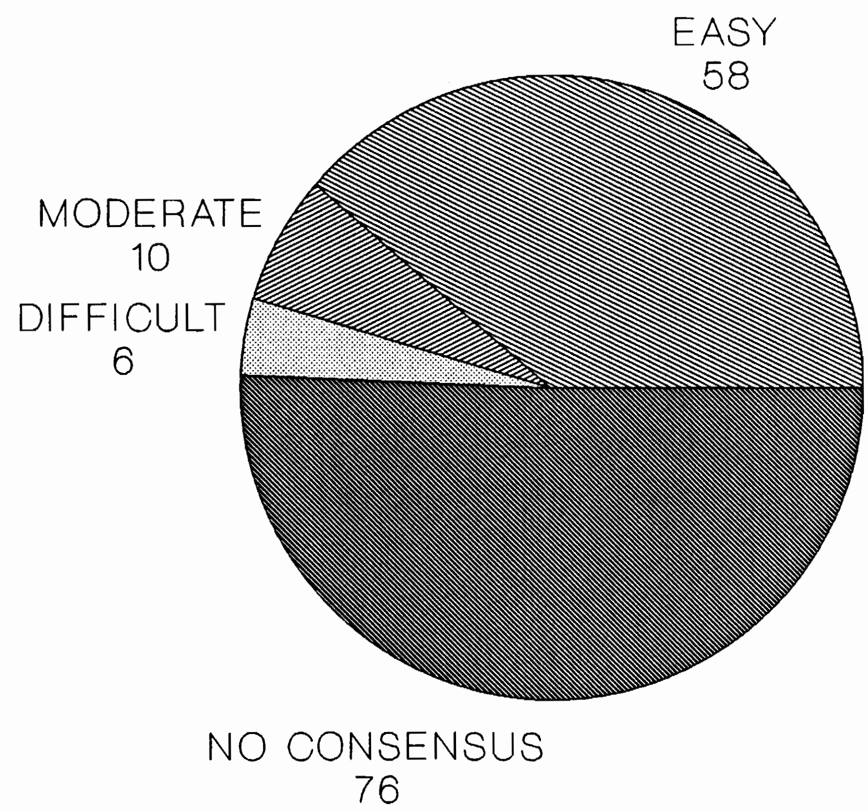

Figure 5.2: GPSS Overall Difficulty

survey. Those attributes are as follows.

<u>AGVS</u>
Collision Avoidance
Control System
Present Location Vehicle
Routing

<u>AS/RS</u>
Dwell Point Strategies

<u>INDUSTRIAL FORK TRUCKS</u>
Collision Avoidance

<u>INDUSTRIAL ROBOTS</u>
Shared Work Envelopes

These are areas which may need further development within GPSS.

5.3.3 PROMODEL Material Handling Modeling Capabilities

Based on the general consensus of respondents, PROMODEL has the ability to model most attributes, but it is incapable of modeling redirection of in-transit AGVs and speed for all degrees of freedom for industrial robots. These are two areas which may require more attention to keep PROMODEL competitive with simulation languages.

Figure 5.3 depicts the modeling method employed when addressing the attributes under study. Based on this histogram, PROMODEL has special constructs for modeling the majority of the conveyor, crane, and fork truck attributes. PROMODEL models nearly half of all other material handling attributes for AGVS, AS/RS, and industrial robots using

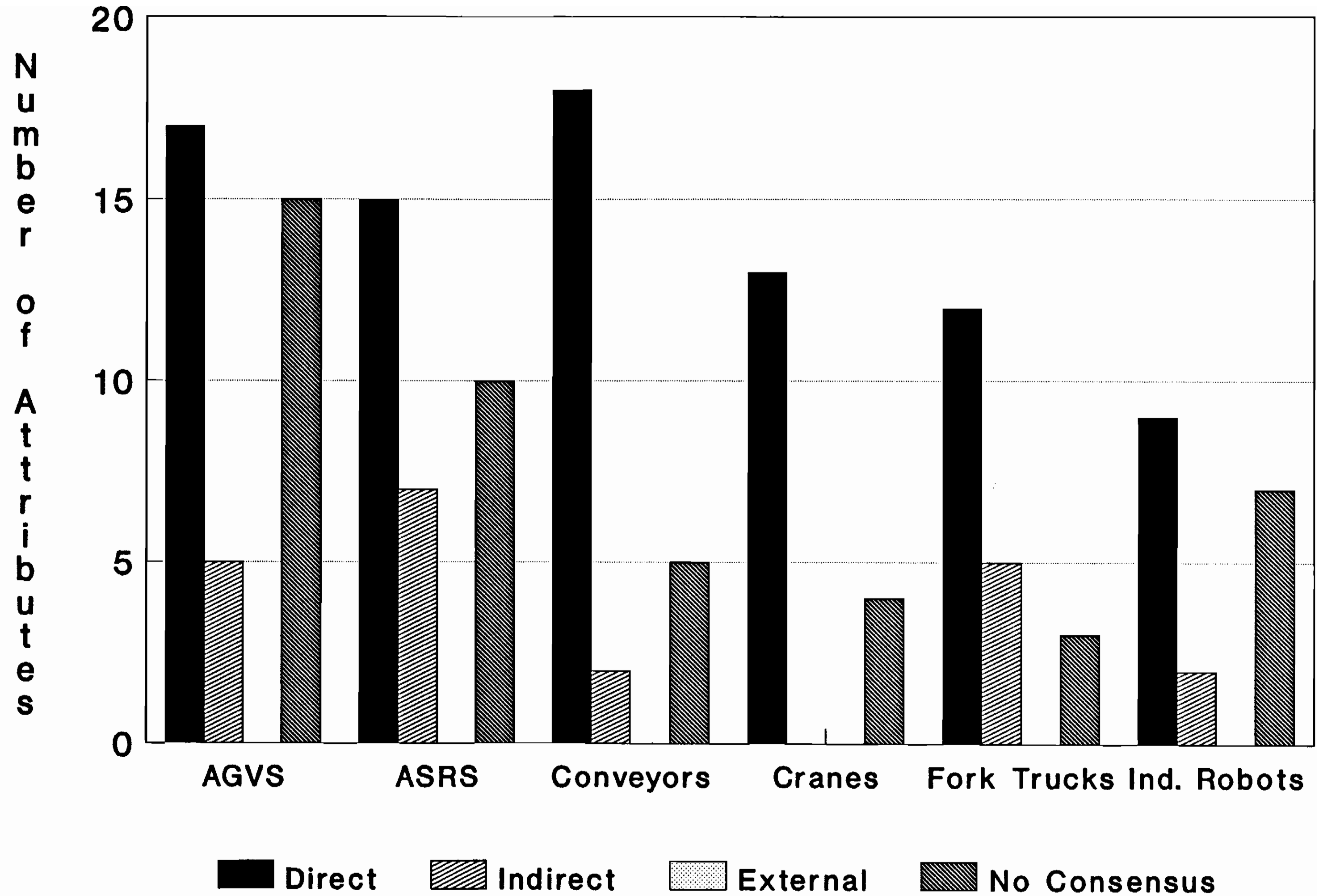

Fig. 5.3: Modeling Methods for PROMODEL

direct means. This is not surprising, because PROMODEL is a simulation program designed for manufacturing systems. The literature review, chapter two, stated that PROMODEL has special constructs for modeling all material handling devices under study. Therefore, one would expect even more attributes to be modeled using special constructs.

The majority of the attributes are considered easy to model when using PROMODEL (See Figure 5.4). Only one attribute was deemed difficult to model. PROMODEL respondents claim the ability to specify lift specifications or the movement of the forks of an industrial fork truck is very difficult to model.

5.3.4 SIMAN Material Handling Modeling Capabilities

According to the general consensus of respondents for SIMAN IV, there are no attributes under study which cannot be modeled using SIMAN IV. Please view Tables 5.2 through 5.7 for verification.

When viewing Figure 5.5 for modeling methods utilized, it is noticed that SIMAN has special constructs which allow one to model the vast majority of AGVS attributes. AS/RS and crane systems are modeled using predominantly indirect, or general, modeling features. Those industrial robot attributes, for which there is a general consensus, are all modeled indirectly. Conveyor and fork truck attributes are modeled using either direct or indirect methods.

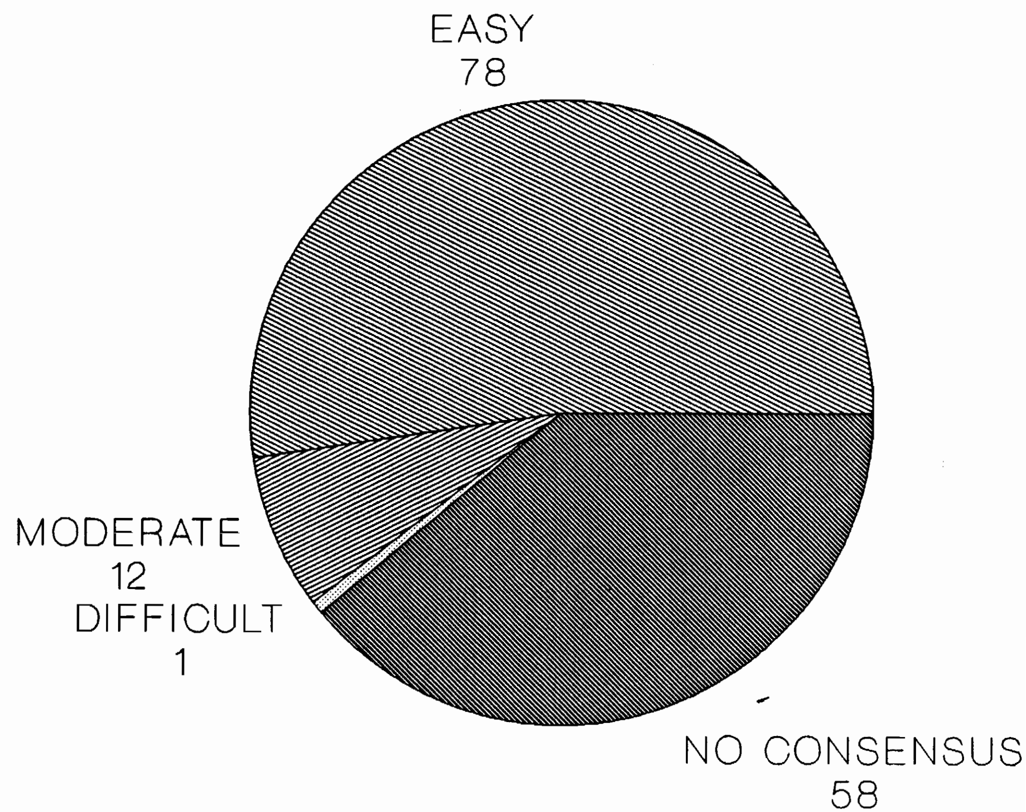

Figure 5.4: PROMODEL Overall Difficulty

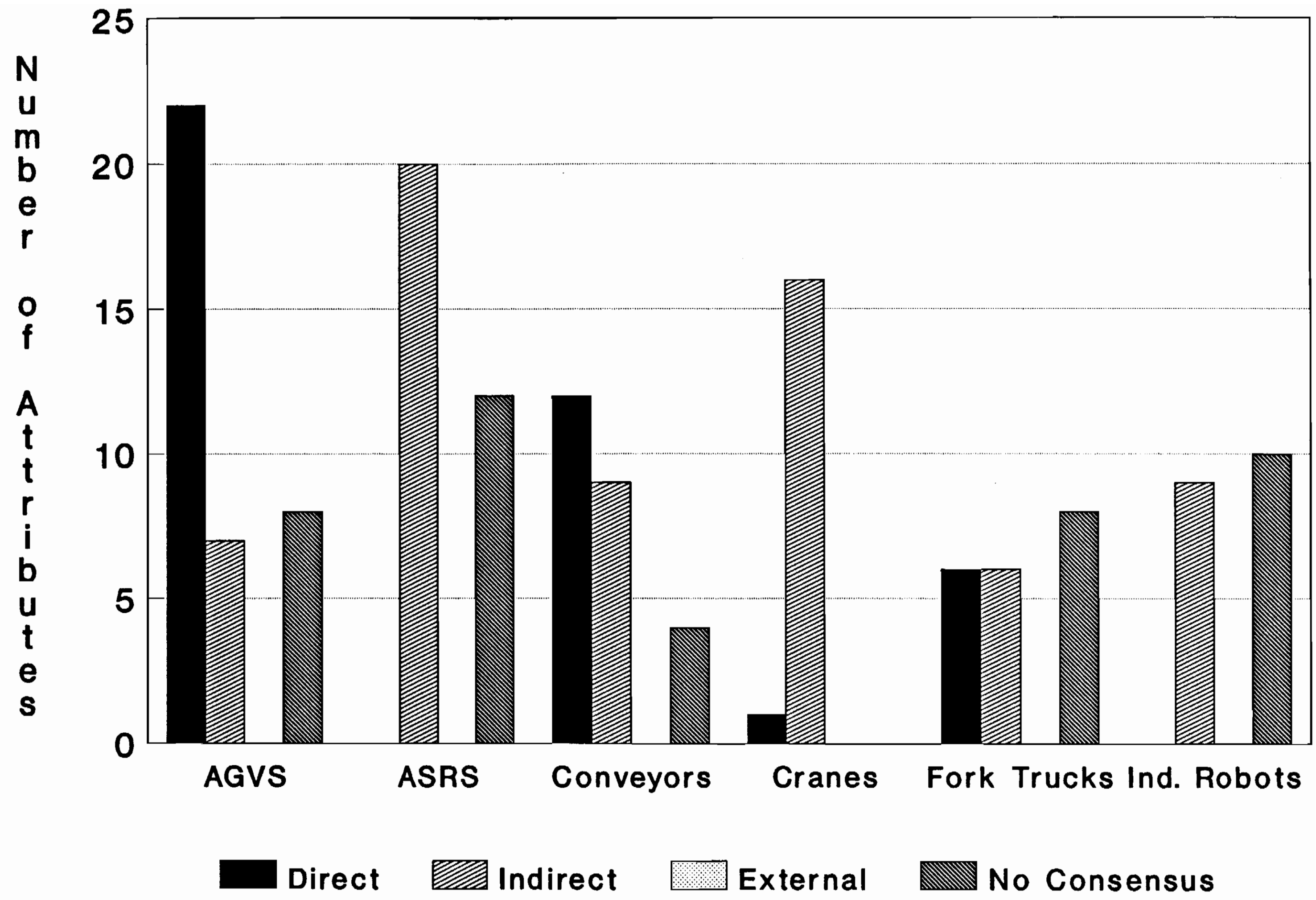

Figure 5.5: Modeling Methods for SIMAN

For the majority of the attributes under study, there was no consensus for the level of difficulty experienced when modeling the attributes. Less than one-third (49/150 total attributes under study, see Figure 5.6) of these attributes were considered easy to model using SIMAN IV.

5.3.5 SLAM II Material Handling Modeling Capabilities

SLAM II models all attributes except four. It appears that the structure of SLAM II does not allow one to model dual shuttles for AS/RS or the transport of multiple loads for cranes. SLAM II also cannot model acceleration and deceleration of fork trucks.

When analyzing the modeling methods utilized (See Figure 5.7), one finds that SLAM models over half of the attributes under study for AGVS and crane systems using special constructs. It indirectly models most of the attributes for conveyors, fork trucks, and industrial robots. AS/RS systems are modeled direct or indirect means depending on the attribute under study. This slightly corresponds to the literature review in chapter two. The literature review revealed that SLAM II has material handling modules for AGVS, AS/RS, and crane systems. The difference based on this analysis is that SLAM II does not directly address over half of the AS/RS attributes under study.

According to survey responses, the following areas are

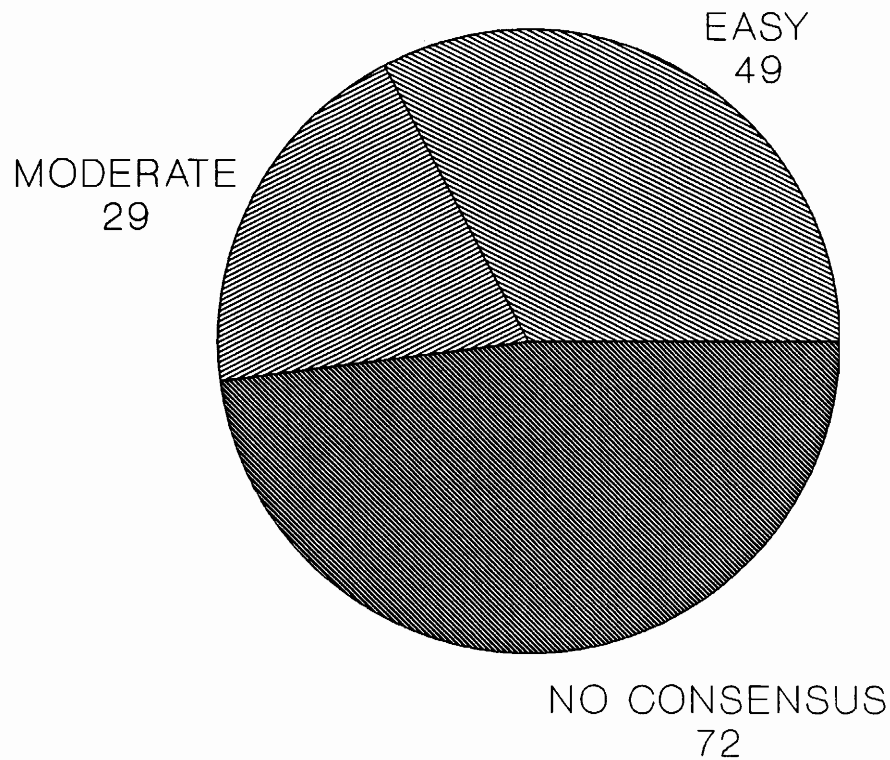

Figure 5.6: SIMAN Overall Difficulty

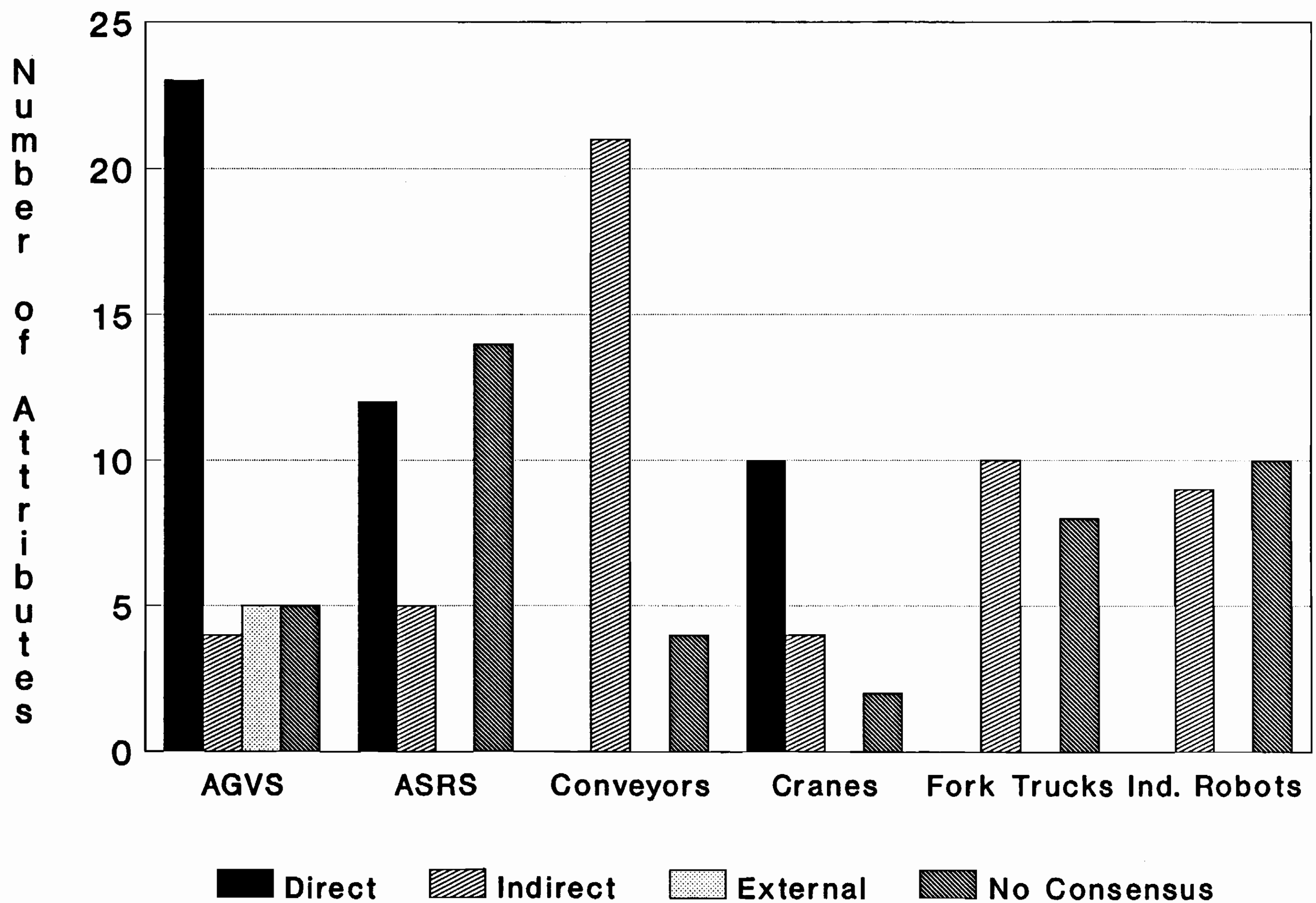

Figure 5.7: Modeling Methods for SLAM

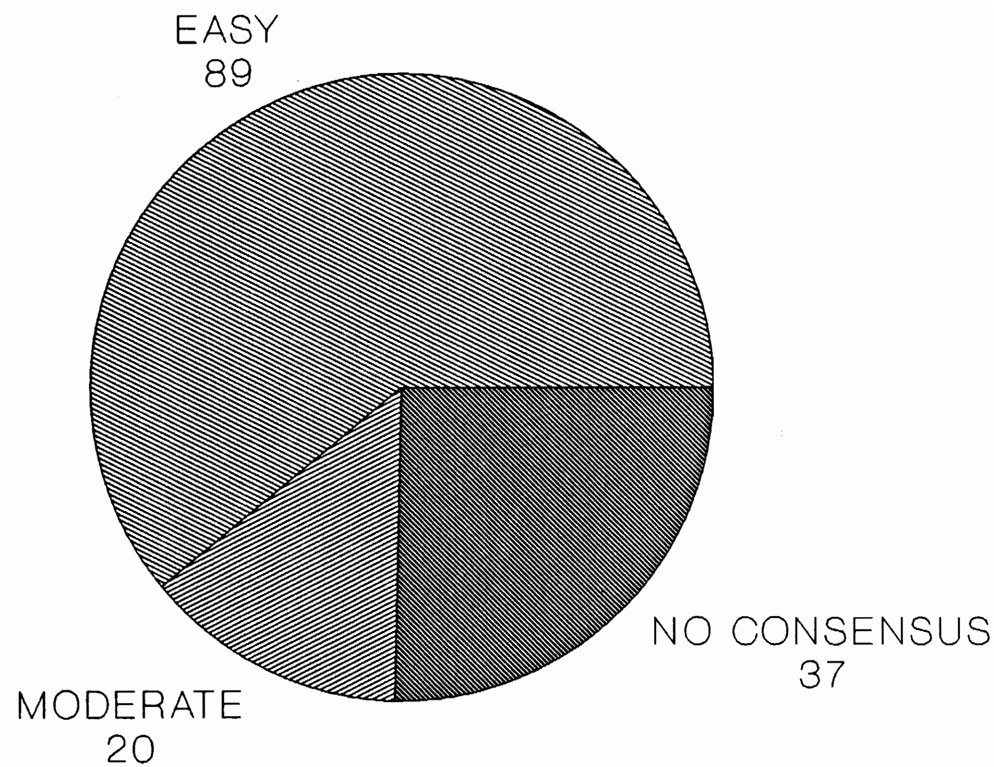

Figure 5.8: SLAM Overall Difficulty

modeled externally when using SLAM II.

AGVS - Control System
Passing
Rerouting
Path Segment Downtime

SLAM II is the only software package which models one or more of the attributes under study using external means.

Respondents for SLAM II state that nearly 60% (89/150 total attributes under study) of the total attributes are easy to model, see Figure 5.8 on the previous page. There were no areas which were deemed difficult to model.

5.4 Assessment of the State-of-the-Art

As stated in the methodology, capabilities of software packages were used to assess the state-of-the-art in modeling material handling systems. Tables 5.2 through 5.7 were utilized to determine attributes which could be modeled by all software packages under study. Those material handling attributes were extracted from the summary tables, Tables 5.2 through 5.7, and are denoted as the capabilities which represent the state-of-the-art in modeling the material handling devices under study. All software packages have the ability to model the following.

Automated Guided Vehicle Systems
Speed
Travel Time
Pick Up Time
Deposit Time
Home Position
Job Search Priorities

Mapping (excluding shortest route)
Shortest Route Mapping
Battery Recharging
Guidepath Layout
Collision Avoidance
Zone Control
Contro System
Vehicle Fleet
Vehicle Limitations on Guidepath
Corrective/Preventive Maintenance
Rerouting
Vehicle Dispatching Rules
Empty Vehicle Management
Varying Part Types

Automated Storage/Retrieval Systems
Storage Rack Configuration
Individual Storage (Bin) Locations
Varying Storage Dimensions
Multiple Loads
Capacity Specifications
Storage Level Determination
Storage Racks on Both Sides
Horizontal Speed
Varying Input/Output Locations
Input/Output Pick Up and Deposit
Storage Pick Up and Deposit
Single and Dual Command Retrieval Sequencing
Preventive Maintenance
Tier Assigned S/R Machines
Zoning

Belt/Roller Conveyors
Conveyor Geometry
Direction of Travel
Conveyor Sections
Speed of Sections
Load Size
Sortation Capabilities
Transfer From Sections
Transfer Off Conveyor
Right Angle Transfer
Loading Time
Unloading Time
Conveyor Capacity
Two Way Belt Conveyor
Loading/Unloading Points
Multiple Entry/Exit Points
Simultaneous Entries/Exits
Accumulation
Loads With Unequal Lengths

Sensors
Preventive and Corrective Maintenance

Gantry Cranes
Bridge Speed
Hoist Speed
Pick Up Time
Deposit Time
Job Search Priority
Simultaneous Hoist and Bridge Travel
Multiple Cranes on Runway
Multiple Cranes in Different Bays
Interference
Idle Crane Management Rules
Corrective and Preventive Maintenance

Industrial Fork Trucks
Speed
Travel Time
Pick Up Time
Deposit Time
Home Position
Job Search Priority
Battery Recharging
Distance/Time Traveled
Corrective and Preventive Maintenance
Load and Fixture Separation

Industrial Robots
Travel Time
Speed
Job Search Priority
Sequence Variation
Pick and Place
Sensors
Multiple Service Stations
Corrective and Preventive Maintenance

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of Results

Each software package has the ability to model many material handling characteristics. Based on the attributes studied for this research the following table best represents the capabilities of the software packages studied. Table 5.8 lists those software packages which directly model over half of the material handling attributes studied for a given device. If a given software has the capability to model over half of the attributes under study for a given device, it is denoted by a "Yes" response. Based on this research, having the ability to model the majority of the attributes using specially designed constructs is quite an achievement for a software package.

Table 5.8: Capabilities for modeling the majority of the attributes under study

	GPSS	PROMODEL	SIMAN IV	SLAM II
Conveyor	Yes	Yes		
Forklift		Yes		
AGVS			Yes	Yes
AS/RS				
Cranes		Yes		Yes
Robots				

Though software developers have made great strides in modeling material handling situations using their respective software, this research revealed some areas which should be addressed to enhance modeling capabilities of the software. It is suggested that software developers address those issues which cannot be modeled, are modeled externally, or are considered difficult to model.

Developers of GPSS may address the ability to model collision avoidance for AGVS and fork trucks. Dwell point strategies for the S/R machine of an AS/RS and shared work envelopes for industrial robots must also be addressed. Other areas which require consideration are the ability to model control systems and present location vehicle routing of AGV systems. According to survey responses, these attributes can be modeled, but users state that it is complex to model these characteristics.

PROMODEL may deem it necessary to address the ability to model the redirection of in-transit vehicles of an AGV system. This is the ability to route a vehicle once it is preempted. Preemption may occur in an AGV system, therefore, users would benefit from the addition of this modeling capability. It may also be beneficial to be able to specify the speed for all degrees of freedom for industrial robots. An enhancement of the capabilities for representing lift specifications for fork trucks would also be beneficial.

Though SIMAN did not have any attributes which were considered impossible, external, or difficult to model, it was realized that much of the modeling of SIMAN was done indirectly. Very few attributes were deemed easy to model. Special constructs for more material handling attributes could make model development easier. This would possibly increase the number users.

SLAM II developers may find it necessary to incorporate the ability to model acceleration, deceleration, dual shuttles for AS/RS systems, and the transport of multiple loads by cranes. Based on responses, the previous attributes can not be modeled using SLAM II. Literature suggests that dual shuttles for AS/RS and multiple loads for cranes do not represent the majority of AS/RS and crane systems in use today. It is believed that with the advances in technology this may one day be commonplace. Therefore, it is important that a simulation software package be equipped to model beyond those issues which are deemed commonplace.

It is also important for SLAM II to address those attributes and operations which are now modeled externally for AGV systems. Those attributes and operations are the following: control system, passing, rerouting, and path segment downtime.

6.2 Recommendations

Based on results received from the survey, it is believed that further analysis which includes responses from Wolverine Software Corporation would prove beneficial to this research area. The sample taken from those who utilize GPSS has a combined experience total of five years. This is less than half of the overall years of experience for either of the other software packages under study.

There is some doubt about the validity of the responses for GPSS. Based on reading and understanding of GPSS, most situations are modelled indirectly, with general resource blocks. Yet responses from surveys contradicted this belief. To verify the indirect modeling of some material handling attributes, representatives of Wolverine Software Corporation were contacted. Inquiries were made about the ability to "map" an automated guided vehicle and the ability to model accumulation. For both of these attributes, the representative stated that they were modeled indirectly. Survey respondents revealed that they were modeled directly. Based on this conversation, it is recommended that a new sample be taken to determine the actual modeling methods for GPSS.

An enhancement to this research would be to clarify the areas where there is no consensus. A larger sample size may reduce the number of "no consensus" responses.

By allowing a panel of experts to complete the survey, it was believed that responses would be similar. This did not occur in all cases. It was discovered that though respondents had frequently utilized the software, they probably never encountered all of the attributes under study. It may be feasible to perform this same study using only software developers who fully understand the capabilities of their respective software package. This may reduce some of the areas with no consensus.

It may be interesting to rate the complexity of modeling each attribute. This is beyond the scope of this research. By giving each attribute a weight it may be found that some software packages only model the easy to model attributes while others can model more complex situations.

Finally, more material handling devices may be studied. This survey focused on specific types of material handling devices. The study of other material handling devices would require an analysis of material handling modeling features similar to the one performed for this research, but the basic survey format may remain the same.

6.3 Contributions

The survey results will give modelers some insight into the capabilities of the four software packages studied (GPSS, PROMODEL, SIMAN, and SLAM II). The identification of the attributes which one may want to model, gives software developers an understanding of what modelers may desire when using their software for material handling purposes. The survey developed may also be utilized for further research purposes.

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APPENDIX

APPENDIX A: SAMPLE SURVEY

1993 SURVEY INFORMATION

for

SIMULATION MODELING OF MATERIAL HANDLING SYSTEMS

Simulation Software Under Study (circle one):

GPSS/H OR GPSS/PC
PROMODEL*PC*
SIMAN IV
SLAM II with MH Extension

Responder's Name_______________________________
Daytime Phone Number___________________________
Years of experience with the above software ______

Dear Survey Participant:

The purpose of this survey is to assess the capabilities of various simulation software packages in modeling specific materials handling devices. Four software packages (SLAM II, GPSS, PROMODEL*PC*, and SIMAN IV) are being studied to determine their capabilities for modeling various material handling operations. This survey will be used as partial fulfillment of research requirements toward a Master of Science degree in Industrial Engineering .

The introduction provides information which is necessary for proper completion of the survey. Therefore, please read the introduction carefully prior to beginning the actual survey.

If there is a section of which you are unfamiliar, omit this section and return the survey with other sections answered.

Please complete and return surveys **before April 30, 1993** to the following address:

Virginia Tech
Industrial and Systems Engr. Dept.
c/o Roderick J. Reasor, Ph.D., P.E.
354 Whittemore Hall
Blacksburg, VA 24061-0118

Early survey responses would be highly appreciated, due to the fact that this would allow earlier data analysis.

Thank you for your time and effort. Your responses are an important part of this research.

Sincerely,

Pamela R. Comer
Candidate for M.S. I.E.

INTRODUCTION

This survey seeks to determine the absence or presence of various capabilities, the modeling method utilized*, and the ease of modeling** for simulation modeling of various material handling operations. This survey is designed to be completed by an expert in the use of the software under study.

Each section denotes the analysis of a different device. All questions are closed-ended, but feel free to elaborate on any situation. Pages are included in the back of the survey for any comments you feel are necessary to better address each section. When referring to a question in the survey please write the section and reference number of the attribute which the comment addresses.

Sections:

- A - Automated Guided Vehicles (AGVS)
- B - Automated Storage and Retrieval Systems (AS/RS)
- C - Belt/Roller Conveyors
- D - Gantry Cranes
- E - Industrial Fork Trucks
- F - Industrial Robots

If there are any questions please contact Pamela Comer
Home: (703) 552-8477
School (703) 231-4926

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* modeling methods are divided into three categories:

<u>directly</u> - special constructs/resources (e.g., a conveyor block) or general material handling constructs (e.g., a transporter) are specially designed to model the material handling device and the specified operation.
<u>indirectly</u> - generic resource blocks or general modeling features are used to model the material handling operation.
<u>externally</u> - general purpose languages (FORTRAN, C, PASCAL, etc.) must be used to model the specified operation; must employ user-written routines to model the given situation

** Please assess the level of difficulty required to model each characteristic in terms of the time and/or lines of code required.

TERMINOLOGY

Section A:
AUTOMATED GUIDED VEHICLE SYSTEMS (AGVS)

1. **Speed** - distance per unit time an AGV travels
2. **Travel Time** - time required to move from one location to another
3. **Pickup Time** - time required to load a part once the AGV has reached the pickup location
4. **Deposit Time** - time required to deposit a load once the AGV has reached the deposit location
5. **Home Position** - location on the guidepath which is designated as the resting point or starting position
6. **Acceleration** - rate in distance per unit time squared at which the AGV starts from a stopped position or the ability to specify the time period required to reach maximum desired speed from a stopped position
7. **Deceleration** - distance per unit time squared at which the AGV stops from traveling at maximum desired speed or the ability to specify the time period required to reach a complete stop when traveling at maximum desired speed
8. **Empty Vehicle Travel Speed** - speed/time of travel for empty vehicles when different from loaded vehicle travel specification
9. **Redirection of In-transit Vehicles** - ability to route an in-transit vehicle directly to another location when vehicle has been preempted
10. **Job Search Priority** - specification of which task to perform first when multiple tasks require an AGV
11. **Mapping (excluding shortest route)** - ability to route vehicle over several possible routes
12. **Shortest Route Mapping** - ability to route a vehicle using the shortest distance between two points
13. **Battery Recharging** - scheduled time and location for recharging of batteries. Batteries may need recharging after a specified period of time, vehicle must be routed to battery charge area
14. **Guidepath Layout** - specification of the entire path on which vehicles may travel, including from/to points and distances between points
15. **Spurs** - a bi-directional segment which extends form the main guidepath for loading, unloading, or waiting; it allows only one vehicle to travel on it at a given time due to its one entrance/exit location
16. **Collision Avoidance** - mechanisms provided to avoid collisions at various areas along the guidepath (i.e. at intersections, pickup/deposit points, and with other material handling devices
17. **Zone control** - dividing segments of the guidepath into non-overlapping sections, in which, only one vehicle is allowed at any given time
18. **Control System** - communication with a controller where assignments and routing decisions are made (i.e. control points)

SECTION A: Automated Guided Vehicle Systems

REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	Modeling Method			Difficulty		
		DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
**	SECTION A: AGVS						
1	SPEED ☐ YES ☐ NO						
2	TRAVEL TIME ☐ YES ☐ NO						
3	PICKUP TIME ☐ YES ☐ NO						
4	DEPOSIT TIME ☐ YES ☐ NO						
5	HOME POSITION ☐ YES ☐ NO						
6	ACCELERATION ☐ YES ☐ NO						
7	DECELERATION ☐ YES ☐ NO						
8	EMPTY VEHICLE TRAVEL SPEED ☐ YES ☐ NO						
9	REDIRECTION OF IN-TRANSIT VEHICLES ☐ YES ☐ NO						
10	JOB SEARCH PRIORITIES ☐ YES ☐ NO						
11	MAPPING (excluding shortest route) ☐ YES ☐ NO						
12	SHORTEST ROUTE MAPPING ☐ YES ☐ NO						
13	BATTERY RECHARGING ☐ YES ☐ NO						
14	GUIDEPATH LAYOUT ☐ YES ☐ NO						
15	SPURS ☐ YES ☐ NO						
16	COLLISION AVOIDANCE ☐ YES ☐ NO						
17	ZONE CONTROL ☐ YES ☐ NO						
18	CONTROL SYSTEM ☐ YES ☐ NO						

19. **Vehicle Fleet** - multiple vehicles sharing the same guidepath and the ability to specify the number of vehicles in the fleet

20. **Homogenous Characteristics of a Fleet**- specifications for speed, vehicle type, pickup/deposit, etc. which allow the user to specify characteristics for all vehicles in the fleet

21. **Multiple Fleets** - specification of different characteristics (speed, vehicle type, etc.) for multiple fleets

22. **Vehicle Limitation on Guidepath** - limitations for the number of vehicles which may simultaneously travel on a segment of a guidepath at any point in time

23. **Onboard operations** - ability to perform an operation while the unit load is located on the AGV

24. **Present Location Vehicle Routing** - determination of the present location of a vehicle and routing it to the next location from its present location on the guidepath

25. **Corrective Maintenance** - unscheduled breakdown and repair of vehicle

26. **Preventive Maintenance** - scheduled downtime for general upkeep

27. **Bi-directional Travel** - ability to route a vehicle in two directions along guidepath segment

28. **Passing** - allowance for vehicles to take a different route when area of travel is blocked or occupied

29. **Rerouting** - capability for sending AGV along a different path when a network segment is down

30. **Path Segment Downtime** - ability to model a segment of the path as being down

31. **Vehicle Dispatching Rules** - determination of where to route vehicle when multiple jobs await

32. **Vehicle Selection**- determination of which vehicle to send to perform a given task (i.e. nearest vehicle, least utilized, etc.)

33. **Empty Vehicle Management** - specification of where to route vehicle when idle

34. **Multiple Loads** - ability to handle multiple loads on a vehicle

35. **Varying Part Types** - retaining identity of parts when various part types are handled

36. **Priorities at Interface Points** - determination of which vehicle has priority at intersection or other interference points

37. **Parameter Status** - methodology which allows each AGV to know the location, routing, load status, etc. of other vehicles in the system to allow the AGV to take any necessary actions

SECTION A: Automated Guided Vehicle Systems

REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	Modeling Method: DIRECT	INDIRECT	EXTERNAL	Difficulty: EASY	MODERATE	DIFFICULT
19	VEHICLE FLEET ☐ YES ☐ NO						
20	HOMOGENOUS CHARACTERISTICS OF A FLEET ☐ YES ☐ NO						
21	MULTIPLE FLEETS ☐ YES ☐ NO						
22	VEHICLE LIMITATIONS ON GUIDEPATH ☐ YES ☐ NO						
23	ONBOARD OPERATIONS ☐ YES ☐ NO						
24	PRESENT LOCATION VEHICLE ROUTING ☐ YES ☐ NO						
25	CORRECTIVE MAINTENANCE ☐ YES ☐ NO						
26	PREVENTIVE MAINTENANCE ☐ YES ☐ NO						
27	BI-DIRECTIONAL TRAVEL ☐ YES ☐ NO						
28	PASSING ☐ YES ☐ NO						
29	REROUTING ☐ YES ☐ NO						
30	PATH SEGMENT DOWNTIME ☐ YES ☐ NO						
31	VEHICLE DISPATCHING RULES ☐ YES ☐ NO						
32	VEHICLE SELECTION ☐ YES ☐ NO						
33	EMPTY VEHICLE MANAGEMENT ☐ YES ☐ NO						
34	MULTIPLE LOADS ☐ YES ☐ NO						
35	VARYING PART TYPES ☐ YES ☐ NO						
36	PRIORITIES AT INTERFACE POINTS ☐ YES ☐ NO						
37	PARAMETER STATUS ☐ YES ☐ NO						

TERMINOLOGY

Section B:

AUTOMATED STORAGE AND RETRIEVAL SYSTEM (AS/RS)

1. **Storage Rack Configuration** - specification of the number of rows and columns or the length of aisles and height of racks
2. **Individual Storage (Bin) Locations** - identification for the locations of each bin in the system (i.e. row 5, column 6)
3. **Individual Storage Dimensions** - specification for height, width, and depth of bins
4. **Varying Storage Dimensions** - on a given rack, a specified section of bins has different storage capabilities
5. **Multiple Loads** - ability of an individual storage location to hold more than one unit load
6. **Capacity Specification** - ability to input the maximum capacity (quantity/weight) for each storage bin
7. **Shuffle Cycles for Double Deep Bins** - when multiple unit loads are stored in a bin and the load which is stored in back is desired the front load must be removed and relocated prior to picking the desired load
8. **Storage Policies** - ability to select a bin for storage based on various choices (i.e. closest available bin, closest avail bin nearest its first workstation, dedicated storage, randomized storage, etc.)
9. **Storage Level Determination** - calculation of present capacity to determine reorder point
10. **Storage Racks on Both Sides** - modeling storage racks on both sides of the aisle
11. **Retrieval Policies** - ability to retrieve items based on various policies (i.e. priority specifications, first in first out, etc.)
12. **Part Locating Capabilities** - ability to locate desired material and keep track of where parts are stored when different part types are stored in the AS/RS
13. **Vertical Speed (hoisting)** - distance traveled per unit time in the vertical direction
14. **Horizontal Speed (cruising)** - distance traveled per unit time in the horizontal direction
15. **Acceleration** - rate in distance per unit time squared or the time period required to reach maximum desired speed from a stopped position
16. **Deceleration** - distance per unit time squared or the time period required to reach a complete stop when traveling a maximum desired speed
17. **Simultaneous Horizontal and Vertical Travel** - the ability to represent simultaneous horizontal and vertical travel

SECTION B: Automated Storage and Retrieval Systems

REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	Modeling Method: DIRECT	INDIRECT	EXTERNAL	Difficulty: EASY	MODERATE	DIFFICULT
**	SECTION B: AS/RS						
1	STORAGE RACK CONFIGURATION ☐ YES ☐ NO						
2	INDIVIDUAL STORAGE (BIN) LOCATIONS ☐ YES ☐ NO						
3	INDIVIDUAL STORAGE DIMENSIONS ☐ YES ☐ NO						
4	VARYING STORAGE DIMENSIONS ☐ YES ☐ NO						
5	MULTIPLE LOADS ☐ YES ☐ NO						
6	CAPACITY SPECIFICATION ☐ YES ☐ NO						
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS ☐ YES ☐ NO						
8	STORAGE POLICIES ☐ YES ☐ NO						
9	STORAGE LEVEL DETERMINATION ☐ YES ☐ NO						
10	STORAGE RACKS ON BOTH SIDES ☐ YES ☐ NO						
11	RETRIEVAL POLICIES ☐ YES ☐ NO						
12	PART LOCATING CAPABILITIES ☐ YES ☐ NO						
13	VERTICAL SPEED (hoisting) ☐ YES ☐ NO						
14	HORIZONTAL SPEED (cruising) ☐ YES ☐ NO						
15	ACCELERATION ☐ YES ☐ NO						
16	DECELERATION ☐ YES ☐ NO						
17	SIMULTANEOUS HORIZONTAL AND VERTICAL TRAVEL ☐ YES ☐ NO						

18. **Varying Input/Output (I/O) Locations** - pickup and deposits occur at opposite ends of aisle, same end of aisle, varying elevations, etc.
19. **I/O Pick Up** - time required to pick up a load from the I/O point
20. **Storage Pick Up** - time required to retrieve a load from an individual storage location
21. **I/O Deposit** - time required to deposit a load at the I/O point
22. **Storage Deposit** - time required to deposit a load in an individual storage location
23. **Dwell Point Strategies** - specification of where to route S/R machine when idle
24. **Single Command Retrieval Sequencing** - a single storage or retrieval is performed and the S/R machine returns to the I/O location
25. **Dual Command Retrieval Sequencing** - a storage and a retrieval are performed in the same cycle and returns to the I/O location; interleaving
26. **Corrective Maintenance** - unscheduled breakdown and repair of S/R machine
27. **Preventative Maintenance** - scheduled downtime for general upkeep
28. **Dual Shuttles** - the S/R machine can carry two loads at once and store each load in different locations
29. **Multiple S/R Machines** - multiple S/R machines on the same track
30. **Tier Assigned S/R machines** - multiple S/R machines are used and each machine is assigned a certain group of rows
31. **Aisle Transfer Car** - a common S/R machine is used for multiple aisles, must model movement from one aisle to the next
32. **Zoning** - partitioning of storage racks so different items may be stored in designated areas

SECTION B: Automated Storage and Retrieval Systems

REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	Modeling Method			Difficulty		
		DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
18	VARYING INPUT/OUTPUT (I/O) LOCATIONS ☐ YES ☐ NO						
19	I/O PICK UP ☐ YES ☐ NO						
20	STORAGE PICK UP ☐ YES ☐ NO						
21	I/O DEPOSIT ☐ YES ☐ NO						
22	STORAGE DEPOSIT ☐ YES ☐ NO						
23	DWELL POINT STRATEGIES ☐ YES ☐ NO						
24	SINGLE COMMAND RETRIEVAL SEQUENCING ☐ YES ☐ NO						
25	DUAL COMMAND RETRIEVAL SEQUENCING ☐ YES ☐ NO						
26	CORRECTIVE MAINTENANCE ☐ YES ☐ NO						
27	PREVENTIVE MAINTENANCE ☐ YES ☐ NO						
28	DUAL SHUTTLES ☐ YES ☐ NO						
29	MULTIPLE S/R MACHINES ☐ YES ☐ NO						
30	TIER ASSIGNED S/R MACHINES☐ YES ☐ NO						
31	AISLE TRANSFER CAR ☐ YES ☐ NO						
32	ZONING ☐ YES ☐ NO						

TERMINOLOGY

Section C:

BELT/ROLLER CONVEYORS

1. **Conveyor Geometry** - layout of the conveyor; path of travel
2. **Direction of Travel** - specification of the direction in which the conveyor is moving
3. **Conveyor Sections** - identification of separate sections which often make up a conveyor
4. **Speed of Sections** - specification of the rate of travel for each conveyor section
5. **Load Size** - ability to specify the dimensions of the load for spacing purposes
6. **Spacing of Loads** - maintaining a set or minimum distance between loads on the conveyor
7. **Sortation Capabilities** - ability to distinguish different loads on the conveyor and separate them according to part type
8. **Onboard Operations** - performance of operations while entity is located on the conveyor; no transfer time is necessary
9. **Transfer from Sections** - ability to specify time required to move a load from one conveyor section to another
10. **Transfer Off Conveyor** - ability to specify time required to move a load from conveyor to a location off of the conveyor
11. **Right Angle Transfer** - movement of the load to a location which is at a right angle to its direction of travel on the conveyor
12. **Loading Time** - time required for placing a load onto the conveyor
13. **Unloading Time** - time required to remove a load from the conveyor
14. **Conveyor Capacity** - maximum number of loads allowed on a conveyor section
15. **Bi-directional Transfer** - ability to transfer entities in two separate directions
16. **Two Way Belt Conveyor** - a bottom belt also conveys loads
17. **Loading/Unloading Points** - ability to specify the position of loading and unloading points at any point along the conveyor
18. **Multiple Entry /Exit Points** - loads are placed on the conveyor at various locations and loads are removed from various points on the conveyor
19. **Simultaneous Entries/Exits** - allowing multiple entries/exits to occur at the same time; simultaneous entity creations
20. **Accumulation** - loads are allowed to continue travel even when the leading load is impeded
21. **Transport** - loads maintain spacing at all times

SECTION C: Belt/Roller Conveyors

REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	Modeling Method: DIRECT	INDIRECT	EXTERNAL	Difficulty: EASY	MODERATE	DIFFICULT
**	SECTION C: BELT/ROLLER CONVEYORS						
1	CONVEYOR GEOMETRY ☐ YES ☐ NO						
2	DIRECTION OF TRAVEL ☐ YES ☐ NO						
3	CONVEYOR SECTIONS ☐ YES ☐ NO						
4	SPEED OF SECTIONS ☐ YES ☐ NO						
5	LOAD SIZE ☐ YES ☐ NO						
6	SPACING OF LOADS ☐ YES ☐ NO						
7	SORTATION CAPABILITIES ☐ YES ☐ NO						
8	ONBOARD OPERATIONS ☐ YES ☐ NO						
9	TRANSFER FROM SECTIONS ☐ YES ☐ NO						
10	TRANSFER OFF CONVEYOR ☐ YES ☐ NO						
11	RIGHT ANGLE TRANSFER ☐ YES ☐ NO						
12	LOADING TIME ☐ YES ☐ NO						
13	UNLOADING TIME ☐ YES ☐ NO						
14	CONVEYOR CAPACITY ☐ YES ☐ NO						
15	BI-DIRECTIONAL TRANSFER ☐ YES ☐ NO						
16	TWO WAY BELT CONVEYOR ☐ YES ☐ NO						
17	LOADING/UNLOADING POINTS ☐ YES ☐ NO						
18	MULTIPLE ENTRY/EXIT POINTS☐ YES ☐ NO						
19	SIMULTANEOUS ENTRIES/EXITS☐ YES ☐ NO						
20	ACCUMULATION ☐ YES ☐ NO						
21	TRANSPORT ☐ YES ☐ NO						

22. **Loads with Unequal Lengths** - movement of parts along conveyor with varying lengths, especially when spacing is required on transport conveyors

23. **Sensors** - sensing capabilities which serve as control points where decisions are made for the routing of each part

24. **Preventive Maintenance** - unscheduled breakdown and repair of conveyor

25. **Corrective Maintenance** - scheduled downtime for general upkeep

SECTION C: Belt/Roller Conveyors

		Modeling Method			Diffi- culty		
REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
22	LOADS WITH UNEQUAL LENGTHS ☐ YES ☐ NO						
23	SENSORS ☐ YES ☐ NO						
24	PREVENTIVE MAINTENANCE ☐ YES ☐ NO						
25	CORRECTIVE MAINTENANCE ☐ YES ☐ NO						

TERMINOLOGY

Section D:

GANTRY CRANES

1. **Bridge Speed** - distance traveled per unit time by the bridge of the crane
2. **Hoist Speed** - distance traveled per unit time by the hoist of the crane
3. **Picking Device** - movement (speed or time) of the picking device
4. **Acceleration (Bridge and Hoist)** - rate in distance per unit time squared or the time period required to reach maximum desired speed from a stopped position
5. **Deceleration (Bridge and Hoist)**- distance per unit time squared or the time period required to reach a complete stop when traveling a maximum desired speed
6. **Pick Up Time** - time required to pick up (and position, if necessary) a load once the crane has reached the pick up location (may include movement of picking device)
7. **Deposit Time** - time required to deposit (and position, if necessary) a load once the crane has reached the deposit location (may include movement of picking device)
8. **Positioning** - locating the area for pickup or deposit; specification of the distance of travel for the bridge and the hoist to reach desired location
9. **Job Search Priority** - specification of which job to perform first when multiple tasks require a crane
10. **Simultaneous Hoist and Bridge Movement** - ability to represent simultaneous bridge and hoist travel
11. **Multiple Cranes on Runway** - more than one crane share the same runway and the same work envelope
12. **Multiple Cranes in Different Bays** - modeling simultaneous yet independently operating crane systems in different bays which share the same reference point from which destinations are identified
13. **Interference** - determination of when a crane must wait or move to allow another crane to complete its operations
14. **Idle Crane Management Rules** - specification of where to route crane when idle
15. **Corrective Maintenance** - unscheduled breakdown and repair of crane
16. **Preventive Maintenance** - scheduled downtime for general upkeep
17. **Transport of Multiple Loads** - carrying more than one load and transporting each to different locations

SECTION D: Gantry Cranes

REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	Modeling Method			Difficulty		
		DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
**	SECTION D: GANTRY CRANES						
1	BRIDGE SPEED ☐ YES ☐ NO						
2	HOIST SPEED ☐ YES ☐ NO						
3	PICKING DEVICE ☐ YES ☐ NO						
4	ACCELERATION (bridge & hoist) ☐ YES ☐ NO						
5	DECELERATION (bridge & hoist) ☐ YES ☐ NO						
6	PICK UP TIME ☐ YES ☐ NO						
7	DEPOSIT TIME ☐ YES ☐ NO						
8	POSITIONING ☐ YES ☐ NO						
9	JOB SEARCH PRIORITY ☐ YES ☐ NO						
10	SIMULTANEOUS HOIST AND BRIDGE MOVEMENT ☐ YES ☐ NO						
11	MULTIPLE CRANES ON RUNWAY ☐ YES ☐ NO						
12	MULTIPLE CRANES IN DIFFERENT BAYS ☐ YES ☐ NO						
13	INTERFERENCE ☐ YES ☐ NO						
14	IDLE CRANE MANAGEMENT RULES ☐ YES ☐ NO						
15	CORRECTIVE MAINTENANCE ☐ YES ☐ NO						
16	PREVENTIVE MAINTENANCE ☐ YES ☐ NO						
17	TRANSPORT OF MULTIPLE LOADS ☐ YES ☐ NO						

TERMINOLOGY

Section E:

INDUSTRIAL FORK TRUCKS

1. **Speed** - distance per unit time traveled
2. **Travel Time** - time required to move from one location to another
3. **Pick Up Time** - time required to pick up (and position, if necessary) a load once the truck has reached the pick up location
4. **Deposit Time** - time required to deposit (and position, if necessary) a load once the truck has reached the deposit location
5. **Home Position** - location which is designated as the resting point or starting position
6. **Acceleration** - the rate in distance per unit time squared or the time period required to reach maximum desired speed from a stopped position
7. **Deceleration** - rate in distance per unit time squared or the time period required to reach a complete stop when traveling a maximum desired speed
8. **Lift Specifications** - movement specifications required by the forks of the truck (i.e. elevation, speed of forks, etc.)
9. **Job Search Priority** - specification of which task to perform first when multiple tasks require a fork lift truck
10. **Battery Recharging** - time required and routing of vehicle to charging area
11. **Distance/Time Traveled** - distance or time specifications to reach destination
12. **Varying Speeds** - varying speeds when loaded and unloaded
13. **Collision Avoidance** - mechanisms provided to avoid collisions with other material handling devices
14. **Path** - specification of rout to travel to reach destination
15. **Passing** - allowance for vehicles to take a different route when area of travel is blocked or occupied
16. **Routing from Present Location** - ability to route truck to its next assignment from its location anywhere in the system
17. **Vehicle Selection** - determination of which vehicle to send to perform a given task (i.e. nearest, least utilized, etc.)
18. **Corrective Maintenance** - unscheduled breakdown and repair of vehicle
19. **Preventive Maintenance** - scheduled downtime for general upkeep
20. **Load and Fixture Separation** - ability to separate fixtures and parts (i.e. pallets and loads) and then threat them as separate entities

SECTION E: Industrial Fork Trucks

REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	Modeling Method: DIRECT	INDIRECT	EXTERNAL	Difficulty: EASY	MODERATE	DIFFICULT
**	SECTION E: INDUSTRIAL FORK TRUCKS						
1	SPEED ☐ YES ☐ NO						
2	TRAVEL TIME ☐ YES ☐ NO						
3	PICK UP TIME ☐ YES ☐ NO						
4	DEPOSIT TIME ☐ YES ☐ NO						
5	HOME POSITION ☐ YES ☐ NO						
6	ACCELERATION ☐ YES ☐ NO						
7	DECELERATION ☐ YES ☐ NO						
8	LIFT SPECIFICATIONS ☐ YES ☐ NO						
9	JOB SEARCH PRIORITY ☐ YES ☐ NO						
10	BATTERY RECHARGING ☐ YES ☐ NO						
11	DISTANCE/TIME TRAVELED ☐ YES ☐ NO						
12	VARYING SPEEDS ☐ YES ☐ NO						
13	COLLISION AVOIDANCE ☐ YES ☐ NO						
14	PATH ☐ YES ☐ NO						
15	PASSING ☐ YES ☐ NO						
16	ROUTING FROM PRESENT LOCATION ☐ YES ☐ NO						
17	VEHICLE SELECTION ☐ YES ☐ NO						
18	CORRECTIVE MAINTENANCE ☐ YES ☐ NO						
19	PREVENTIVE MAINTENANCE ☐ YES ☐ NO						
20	LOAD AND FIXTURE SEPARATION ☐ YES ☐ NO						

TERMINOLOGY

Section F:

INDUSTRIAL ROBOTS

1. **Home Position** - location (orientation) which is designated as the resting point or starting position
2. **Multiple Degrees of Freedom** - movement in many directions which is accomplished by powered joints
3. **Vertical Traverse** - the ability to represent the movement of the wrist up or down
4. **Radial Traverse** - the ability to represent the in or out movement of the arm from the vertical center of the industrial robot
5. **Rotational Traverse** - the ability to represent the rotation of the arm around the vertical center of the industrial robot
6. **Travel Time** - time required to reach destination from home position and vice versa
7. **Speed** - representation of the distance per unit time of movement
8. **Speed for All Degrees of Freedom** - representation of the speed in vertical, radial, and rotational traverses
9. **Path Logic** - specification of the path which must be taken to reach 10. destination and perform operations
10. **Multiple Tasks Performed** - multiple tasks, thus multiple operation durations, for a given robot
11. **Job Search Priorities** - specification of which task to perform first when multiple tasks require a robot
12. **Sequence Variation** - performance of tasks in different sequences
13. **Pick and Place** - performance of basic pick and place operations
14. **Multiple Grasping Attempts** - modeling the attempts to pick up a part with possible failure included
15. **Sensors** - sensing capabilities which serve as control points where decisions are made for the next action required
16. **Shared Work Envelope** - multiple robots share part of the same work envelope
17. **Multiple Service Stations** - when performing different tasks, the robot may need to rotate on its base and reposition itself to reach the next task
18. **Corrective Maintenance** - unscheduled breakdowns and repair of robot
19. **Preventive Maintenance** - scheduled downtime for general upkeep

SECTION F: Industrial Robots

REFERENCE	Can the following material handling operations be modeled using this software package (yes or no)? If yes, is this operation modeled by using direct, indirect, or external means? What is the level of difficulty experienced when modeling each situation (easy, moderate, difficult)?	Modeling Method: DIRECT	INDIRECT	EXTERNAL	Difficulty: EASY	MODERATE	DIFFICULT
**	SECTION F: INDUSTRIAL ROBOTS						
1	HOME POSITION ☐ YES ☐ NO						
2	MULTIPLE DEGREES OF FREEDOM ☐ YES ☐ NO						
3	VERTICAL TRAVERSE ☐ YES ☐ NO						
4	RADIAL TRAVERSE ☐ YES ☐ NO						
5	ROTATIONAL TRAVERSE ☐ YES ☐ NO						
6	TRAVEL TIME ☐ YES ☐ NO						
7	SPEED ☐ YES ☐ NO						
8	SPEED FOR ALL DEGREES OF FREEDOM ☐ YES ☐ NO						
9	PATH LOGIC ☐ YES ☐ NO						
10	MULTIPLE TASKS PERFORMED ☐ YES ☐ NO						
11	JOB SEARCH PRIORITIES ☐ YES ☐ NO						
12	SEQUENCE VARIATION ☐ YES ☐ NO						
13	PICK AND PLACE ☐ YES ☐ NO						
14	MULTIPLE GRASPING ATTEMPTS ☐ YES ☐ NO						
15	SENSORS ☐ YES ☐ NO						
16	SHARED WORK ENVELOPE ☐ YES ☐ NO						
17	MULTIPLE SERVICE STATIONS ☐ YES ☐ NO						
18	CORRECTIVE MAINTENANCE ☐ YES ☐ NO						
19	PREVENTIVE MAINTENANCE ☐ YES ☐ NO						

COMMENTS

Please begin each comment using section and reference number. Example: (A21) means you are referring to Multiple Fleets of AGVS

APPENDIX B: RAW DATA OF SURVEY RESPONSES

GPSS

SECTION A: AUTOMATED GUIDED VEHICLE SYSTEMS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	2	2			2		1	1	
2	TRAVEL TIME	2	2		2			2		
3	PICKUP TIME	2	2		2			2		
4	DEPOSIT TIME	2	2		2			2		
5	HOME POSITION	2	2			2		1	1	
6	ACCELERATION	2	1	1		1		1		
7	DECELERATION	2	1	1		1		1		
8	EMPTY VEHICLE TRAVEL SPEED	2	2			2		1		1
9	REDIRECTION OF IN-TRANSIT VEHICLES	2	2		2			2		
10	JOB SEARCH PRIORITIES	2	2		2			2		
11	MAPPING (excluding shortest route)	1	1		1			1		
12	SHORTEST ROUTE MAPPING	1	1		1			1		
13	BATTERY RECHARGING	2	2		2			2		
14	GUIDEPATH LAYOUT	2	2		1	1		1		1
15	SPURS	2	1	1	1			1		
16	COLLISION AVOIDANCE	2	2			2				2
17	ZONE CONTROL	2	2			2			1	1
18	CONTROL SYSTEM	1	1			1				1
19	VEHICLE FLEET	2	2		2			2		
20	HOMOGENOUS CHARACTERISTICS OF FLEET	2	1	1	1			1		
21	MULTIPLE FLEETS	2	1	1	1			1		
22	VEHICLE LIMITATIONS ON GUIDEPATH	2	2		1	1		2		
23	ONBOARD OPERATIONS	2	2		2			2		
24	PRESENT LOCATION VEHICLE ROUTING	2	2			2				2
25	CORRECTIVE MAINTENANCE	2	2		2			1	1	
26	PREVENTIVE MAINTENANCE	2	2		2			2		
27	BI-DIRECTIONAL TRAVEL	2	1	1		1		1		
28	PASSING	2	1	1		1			1	
29	REROUTING	2	2		1	1			2	
30	PATH SEGMENT DOWNTIME	2	2		2			2		
31	VEHICLE DISPATCHING RULES	2	2		1	1			1	1
32	VEHICLE SELECTION	2	1	1		1			1	
33	EMPTY VEHICLE MANAGEMENT	2	2		1	1		1	1	
34	MULTIPLE LOADS	2	2		1	1		2		
35	VARYING PART TYPES	2	2		2			2		
36	PRIORITIES AT INTERFACE POINTS	2	1	1		1			1	
37	PARAMETER STATUS	2	1	1		1				1

	SECTION B: AUTOMATED STORAGE/RETRIEVAL SYSTEMS	SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	STORAGE RACK CONFIGURATION	2	2		1	1		1		1
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	2	2		2			2		
3	INDIVIDUAL STORAGE DIMENSIONS	2	2		1	1		1		1
4	VARYING STORAGE DIMENSIONS	2	2		1	1		1		1
5	MULTIPLE LOADS	2	2			2			1	1
6	CAPACITY SPECIFICATION	2	2		1	1		1		1
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	2	1	1		1			1	
8	STORAGE POLICIES	2	1	1		1			1	
9	STORAGE LEVEL DETERMINATION	2	2			2		1		1
10	STORAGE RACKS ON BOTH SIDES	2	2			2			1	1
11	RETRIEVAL POLICIES	2	1	1	1			1		
12	PART LOCATING CAPABILITIES	2	2			2		1		1
13	VERTICAL SPEED (hoisting)	1	1			1			1	
14	HORIZONTAL SPEED (cruising)	2	2			2		1	1	
15	ACCELERATION	2	1	1		1		1		
16	DECELERATION	2	1	1		1		1		
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	2	1	1		1			1	
18	VARYING INPUT/OUTPUT LOCATIONS	1	1			1		1		
19	INPUT/OUTPUT PICK UP	2	2		2			2		
20	STORAGE PICK UP	2	2		2			2		
21	INPUT/OUTPUT DEPOSIT	2	2		2			2		
22	STORAGE DEPOSIT	2	2		2			2		
23	DWELL POINT STRATEGIES	2	2			2				2
24	SINGLE COMMAND RETRIEVAL SEQUENCING	1	1			1			1	
25	DUAL COMMAND RETRIEVAL SEQUENCING	2	2			2		1		1
26	CORRECTIVE MAINTENANCE	2	2		2			1	1	
27	PREVENTIVE MAINTENANCE	2	2		2			2		
28	DUAL SHUTTLES	2	2			2			1	1
29	MULTIPLE S/R MACHINES	2	1	1		1				1
30	TIER ASSIGNED S/R MACHINES	2	2		1	1			1	1
31	AISLE TRANSFER CAR	2	2			2			1	1
32	ZONING	2	2			2			1	1

SECTION C: BELT/ROLLER CONVEYORS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	CONVEYOR GEOMETRY	2	2		2			2		
2	DIRECTION OF TRAVEL	2	2		2			2		
3	CONVEYOR SECTIONS	2	2		2			1	1	
4	SPEED OF SECTIONS	2	2			2		1	1	
5	LOAD SIZE	2	2			2		1		1
6	SPACING OF LOADS	2	1	1		1			1	
7	SORTATION CAPABILITIES	2	2		2			2		
8	ONBOARD OPERATIONS	2	1	1	1			1		
9	TRANSFER FROM SECTIONS	2	2		2			2		
10	TRANSFER OFF CONVEYOR	2	2		2			2		
11	RIGHT ANGLE TRANSFER	2	2		2			2		
12	LOADING TIME	2	2		2			2		
13	UNLOADING TIME	2	2		2			2		
14	CONVEYOR CAPACITY	2	2		2			1	1	
15	BI-DIRECTIONAL TRANSFER	1	1			1			1	
16	TWO WAY BELT CONVEYOR	2	2		1	1			2	
17	LOADING/UNLOADING POINTS	2	2		2			1		1
18	MULTIPLE ENTRY/EXIT POINTS	2	2		2			1		1
19	SIMULTANEOUS ENTRIES/EXITS	2	2		2				1	1
20	ACCUMULATION	2	2		2			2		
21	TRANSPORT	2	1	1	1			1		
22	LOADS WITH UNEQUAL LENGTHS	2	2			2			1	1
23	SENSORS	1	1		1			1		
24	PREVENTIVE MAINTENANCE	2	2		2			1	1	
25	CORRECTIVE MAINTENANCE	2	2		2			2		

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SECTION D: GANTRY CRANES		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	BRIDGE SPEED	2	2			2		1		1
2	HOIST SPEED	2	2			2		1		1
3	PICKING DEVICE	2	1	1		1		1		
4	ACCELERATION (bridge & hoist)	2	1	1		1			1	
5	DECELERATION (bridge & hoist)	2	1	1		1			1	
6	PICK UP TIME	2	2		2			2		
7	DEPOSIT TIME	2	2		2			2		
8	POSITIONING	2	1	1		1			1	
9	JOB SEARCH PRIORITY	2	2		2			2		
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	2	2			2			1	1
11	MULTIPLE CRANES ON RUNWAY	2	2		1	1			1	1
12	MULTIPLE CRANES IN DIFFERENT BAYS	2	2		2			1	1	
13	INTERFERENCE	2	2			2			1	1
14	IDLE CRANE MANAGEMENT RULES	2	2		1	1		1	1	
15	CORRECTIVE MAINTENANCE	2	2		2			1	1	
16	PREVENTIVE MAINTENANCE	2	2		2			2		
17	TRANSPORT OF MULTIPLE LOADS	2	2			2			2	

SECTION E: INDUSTRIAL FORK TRUCKS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	2	2			2			1	1
2	TRAVEL TIME	2	2		2			2		
3	PICK UP TIME	2	2		2			2		
4	DEPOSIT TIME	2	2		2			2		
5	HOME POSITION	2	2		2			2		
6	ACCELERATION	2	1	1		1			1	
7	DECELERATION	2	1	1		1			1	
8	LIFT SPECIFICATIONS	2	2		1	1		1	1	
9	JOB SEARCH PRIORITY	2	2		2			2		
10	BATTERY RECHARGING	2	2		1	1		2		
11	DISTANCE/TIME TRAVELED	2	2		1	1		1	1	
12	VARYING SPEEDS	2	2			2		1	1	
13	COLLISION AVOIDANCE	2	2			2				2
14	PATH	2	1	1		1			1	
15	PASSING	2	1	1		1			1	
16	ROUTING FROM PRESENT LOCATION	2	1	1		1			1	
17	VEHICLE SELECTION	2	1	1		1			1	
18	CORRECTIVE MAINTENANCE	2	2		2			1	1	
19	PREVENTIVE MAINTENANCE	2	2		2			2		
20	LOAD AND FIXTURE SEPARATION	1	1		1			1		

GPSS

SECTION F: INDUSTRIAL ROBOTS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	HOME POSITION	1	1		1			1		
2	MULTIPLE DEGREES OF FREEDOM	1	1			1			1	
3	VERTICAL TRAVERSE	1	1			1		1		
4	RADIAL TRAVERSE	1	1			1		1		
5	ROTATIONAL TRAVERSE	1	1			1		1		
6	TRAVEL TIME	1	1			1		1		
7	SPEED	1	1			1		1		
8	SPEED FOR ALL DEGREES OF FREEDOM	1	1			1		1		
9	PATH LOGIC	1	1			1			1	
10	MULTIPLE TASKS PERFORMED	1	1			1			1	
11	JOB SEARCH PRIORITIES	1	1		1			1		
12	SEQUENCE VARIATION	1	1			1			1	
13	PICK AND PLACE	1	1			1		1		
14	MULTIPLE GRASPING ATTEMPTS	1	1			1		1		
15	SENSORS	1	1			1			1	
16	SHARED WORK ENVELOPE	1	1			1				1
17	MULTIPLE SERVICE STATIONS	1	1			1			1	
18	CORRECTIVE MAINTENANCE	1	1		1			1		
19	PREVENTIVE MAINTENANCE	1	1		1			1		

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SECTION A: AUTOMATED GUIDED VEHICLE SYSTEMS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	3	3		3			3		
2	TRAVEL TIME	3	3		3			3		
3	PICKUP TIME	3	3		3			3		
4	DEPOSIT TIME	3	3		3			3		
5	HOME POSITION	3	3		3			3		
6	ACCELERATION	3	3		3			3		
7	DECELERATION	3	3		3			3		
8	EMPTY VEHICLE TRAVEL SPEED	2	1	1	1			1		
9	REDIRECTION OF IN-TRANSIT VEHICLES	1		1		1			1	
10	JOB SEARCH PRIORITIES	3	3		3			1	1	
11	MAPPING (excluding shortest route)	3	3		2			1		1
12	SHORTEST ROUTE MAPPING	2	2		1			1		
13	BATTERY RECHARGING	3	3			3		3		
14	GUIDEPATH LAYOUT	3	3		2			1	1	
15	SPURS	3	3		1	1		1	1	
16	COLLISION AVOIDANCE	2	2		1	1		1	1	
17	ZONE CONTROL	2	2		2			1	1	
18	CONTROL SYSTEM	2	2		1	1		1		1
19	VEHICLE FLEET	2	2		2			2		
20	HOMOGENOUS CHARACTERISTICS OF FLEET	2	2		2			2		
21	MULTIPLE FLEETS	2	2		2			2		
22	VEHICLE LIMITATIONS ON GUIDEPATH	2	2		1	1		1	1	
23	ONBOARD OPERATIONS	3	3		1			1		
24	PRESENT LOCATION VEHICLE ROUTING	2	1	1		1			1	
25	CORRECTIVE MAINTENANCE	3	3		2	1		2		
26	PREVENTIVE MAINTENANCE	3	3		2	1		2		
27	BI-DIRECTIONAL TRAVEL	2	2		2			2		
28	PASSING	2	1	1	1			1		
29	REROUTING	2	2			2			1	1
30	PATH SEGMENT DOWNTIME	2	2			2			1	1
31	VEHICLE DISPATCHING RULES	2	2		2			2		
32	VEHICLE SELECTION	2	2		1	1		1	1	
33	EMPTY VEHICLE MANAGEMENT	2	2		1			1		
34	MULTIPLE LOADS	2	1	1	1				1	
35	VARYING PART TYPES	2	2		1	1		1	1	
36	PRIORITIES AT INTERFACE POINTS	1	1			1			1	
37	PARAMETER STATUS	2	1	1		1			1	

SECTION B: AUTOMATED STORAGE/RETRIEVAL SYSTEMS		SAMPLE SZ	Modeling Capability: Yes	Modeling Capability: No	Modeling Method: DIRECT	Modeling Method: INDIRECT	Modeling Method: EXTERNAL	Level of Difficulty: EASY	Level of Difficulty: MODERATE	Level of Difficulty: DIFFICULT
1	STORAGE RACK CONFIGURATION	2	2			2			1	1
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	2	2			2			1	1
3	INDIVIDUAL STORAGE DIMENSIONS	2	1	1		1			1	
4	VARYING STORAGE DIMENSIONS	2	2		1	1		1	1	
5	MULTIPLE LOADS	2	2		2			2		
6	CAPACITY SPECIFICATION	2	2		2			2		
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	2	2			2			1	1
8	STORAGE POLICIES	2	2			2			1	1
9	STORAGE LEVEL DETERMINATION	2	2		1	1			1	1
10	STORAGE RACKS ON BOTH SIDES	2	2		1	1		1	1	
11	RETRIEVAL POLICIES	2	2		1	1		1		1
12	PART LOCATING CAPABILITIES	2	2		1	1			1	1
13	VERTICAL SPEED (hoisting)	2	1	1	1			1		
14	HORIZONTAL SPEED (cruising)	2	2		2			2		
15	ACCELERATION	2	2		2			2		
16	DECELERATION	2	2		2			2		
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	2	1	1	1			1		
18	VARYING INPUT/OUTPUT LOCATIONS	2	2		1	1		1		1
19	INPUT/OUTPUT PICK UP	2	2		2			2		
20	STORAGE PICK UP	2	2		2			2		
21	INPUT/OUTPUT DEPOSIT	2	2		2			2		
22	STORAGE DEPOSIT	2	2		2			2		
23	DWELL POINT STRATEGIES	2	2		2			2		
24	SINGLE COMMAND RETRIEVAL SEQUENCING	1	1		1			1		
25	DUAL COMMAND RETRIEVAL SEQUENCING	1	1		1			1		
26	CORRECTIVE MAINTENANCE	2	2		2			2		
27	PREVENTIVE MAINTENANCE	2	2		2			2		
28	DUAL SHUTTLES	2	1	1		1				1
29	MULTIPLE S/R MACHINES	2	2		2			2		
30	TIER ASSIGNED S/R MACHINES	2	2			2			1	1
31	AISLE TRANSFER CAR	2	2			2			1	1
32	ZONING	2	2			2			2	

SECTION C: BELT/ROLLER CONVEYORS		SAMPLE SZ	Modeling Capability: Yes	Modeling Capability: No	Modeling Method: DIRECT	Modeling Method: INDIRECT	Modeling Method: EXTERNAL	Level of Difficulty: EASY	Level of Difficulty: MODERATE	Level of Difficulty: DIFFICULT
1	CONVEYOR GEOMETRY	3	3		3			3		
2	DIRECTION OF TRAVEL	3	3		3			3		
3	CONVEYOR SECTIONS	3	3		2	1		2	1	
4	SPEED OF SECTIONS	3	3		3			3		
5	LOAD SIZE	3	3		3			3		
6	SPACING OF LOADS	3	3		3			3		
7	SORTATION CAPABILITIES	2	2		1	1		1		1
8	ONBOARD OPERATIONS	3	3		2	1		1	2	
9	TRANSFER FROM SECTIONS	3	3		3			2		
10	TRANSFER OFF CONVEYOR	3	3		3			2		
11	RIGHT ANGLE TRANSFER	3	3		1	1		2		
12	LOADING TIME	2	2		2			2		
13	UNLOADING TIME	2	2		2			2	1	
14	CONVEYOR CAPACITY	3	3		1	2		2	1	
15	BI-DIRECTIONAL TRANSFER	3	2	1	2			1		
16	TWO WAY BELT CONVEYOR	1	1			1			1	
17	LOADING/UNLOADING POINTS	3	3		2	1		2	1	
18	MULTIPLE ENTRY/EXIT POINTS	2	2		1	1		2		
19	SIMULTANEOUS ENTRIES/EXITS	2	2		1	1		1		1
20	ACCUMULATION	3	3		3			3		
21	TRANSPORT	3	3		3			3		
22	LOADS WITH UNEQUAL LENGTHS	2	2		1	1		1		1
23	SENSORS	3	3		2	1		2		1
24	PREVENTIVE MAINTENANCE	3	3		2	1		3		
25	CORRECTIVE MAINTENANCE	3	3		2	1		3		

SECTION D: GANTRY CRANES		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	BRIDGE SPEED	3	3		3			3		
2	HOIST SPEED	3	3		3			3		
3	PICKING DEVICE	2	1	1	1			1		
4	ACCELERATION (bridge & hoist)	3	3		3			3		
5	DECELERATION (bridge & hoist)	3	3		3			3		
6	PICK UP TIME	3	3		3			3		
7	DEPOSIT TIME	3	3		3			3		
8	POSITIONING	3	3		3			2	1	
9	JOB SEARCH PRIORITY	3	3		3			3		
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	2	2		1			1		
11	MULTIPLE CRANES ON RUNWAY	3	3		3			1		1
12	MULTIPLE CRANES IN DIFFERENT BAYS	2	2		2			1		
13	INTERFERENCE	2	2		1			1		
14	IDLE CRANE MANAGEMENT RULES	3	3		2	1		2		
15	CORRECTIVE MAINTENANCE	3	3		2	1		3		
16	PREVENTIVE MAINTENANCE	3	3		2	1		3		
17	TRANSPORT OF MULTIPLE LOADS	2	1	1		1			1	

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SECTION E: INDUSTRIAL FORK TRUCKS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	3	3		3			3		
2	TRAVEL TIME	3	3		3			3		
3	PICK UP TIME	3	3		3			3		
4	DEPOSIT TIME	3	3		3			3		
5	HOME POSITION	3	3		3			3		
6	ACCELERATION	3	3		3			3		
7	DECELERATION	3	3		3			3		
8	LIFT SPECIFICATIONS	1	1			1				1
9	JOB SEARCH PRIORITY	3	3		3			3		
10	BATTERY RECHARGING	3	3			3		1	2	
11	DISTANCE/TIME TRAVELED	3	3		3			3		
12	VARYING SPEEDS	2	1	1	1			1		
13	COLLISION AVOIDANCE	2	2		1	1		1	1	
14	PATH	3	3		3			3		
15	PASSING	2	1	1		1			1	
16	ROUTING FROM PRESENT LOCATION	2	2			2			2	
17	VEHICLE SELECTION	1	1			1			1	
18	CORRECTIVE MAINTENANCE	3	3		2	1		3		
19	PREVENTIVE MAINTENANCE	3	3		2	1		3		
20	LOAD AND FIXTURE SEPARATION	3	3			3			2	1

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SECTION F: INDUSTRIAL ROBOTS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	HOME POSITION	2	2		2			2		
2	MULTIPLE DEGREES OF FREEDOM	2	1	1	1			1		
3	VERTICAL TRAVERSE	2	1	1	1			1		
4	RADIAL TRAVERSE	2	1	1	1			1		
5	ROTATIONAL TRAVERSE	2	2		2			2		
6	TRAVEL TIME	2	2		2			2		
7	SPEED	2	2		2			2		
8	SPEED FOR ALL DEGREES OF FREEDOM	1		1						
9	PATH LOGIC	2	2		2			1	1	
10	MULTIPLE TASKS PERFORMED	2	1	1		1			1	
11	JOB SEARCH PRIORITIES	2	2		1	1		1	1	
12	SEQUENCE VARIATION	2	2			2			2	
13	PICK AND PLACE	2	2		2			1	1	
14	MULTIPLE GRASPING ATTEMPTS	2	1	1		1			1	
15	SENSORS	1	1			1			1	
16	SHARED WORK ENVELOPE	2	1	1		1			1	
17	MULTIPLE SERVICE STATIONS	1	1		1				1	
18	CORRECTIVE MAINTENANCE	2	2		2			2		
19	PREVENTIVE MAINTENANCE	2	2		2			2		

SECTION A: AUTOMATED GUIDED VEHICLE SYSTEMS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	4	4		4			4		
2	TRAVEL TIME	4	4		3	1		4		
3	PICKUP TIME	4	4		2	2		4		
4	DEPOSIT TIME	4	4		2	2		4		
5	HOME POSITION	4	4		3	1		3	1	
6	ACCELERATION	4	4		4			3		
7	DECELERATION	4	4		4			3		
8	EMPTY VEHICLE TRAVEL SPEED	4	3	1	3			3		
9	REDIRECTION OF IN-TRANSIT VEHICLES	4	4		2	2			4	
10	JOB SEARCH PRIORITIES	4	4		2	2		3	1	
11	MAPPING (excluding shortest route)	3	3		3			3		
12	SHORTEST ROUTE MAPPING	4	4		4			3	1	
13	BATTERY RECHARGING	3	3			3		3		
14	GUIDEPATH LAYOUT	4	4		4			2	2	
15	SPURS	4	4		3	1		3	1	
16	COLLISION AVOIDANCE	3	3		2	1		2	1	
17	ZONE CONTROL	4	4		3	1		3	1	
18	CONTROL SYSTEM	3	3			3		1	1	1
19	VEHICLE FLEET	4	4		4			4		
20	HOMOGENOUS CHARACTERISTICS OF FLEET	4	4		4			4		
21	MULTIPLE FLEETS	4	4		4			4		
22	VEHICLE LIMITATIONS ON GUIDEPATH	4	4		3	1		3	1	
23	ONBOARD OPERATIONS	4	3	1	1	2		1	2	
24	PRESENT LOCATION VEHICLE ROUTING	3	3		2	1		2	1	
25	CORRECTIVE MAINTENANCE	4	4			3		1	2	1
26	PREVENTIVE MAINTENANCE	4	4		2	2		3	1	
27	BI-DIRECTIONAL TRAVEL	4	4		3	1		2	2	
28	PASSING	4	3	1	1	2			3	
29	REROUTING	4	3	1		3			3	
30	PATH SEGMENT DOWNTIME	4	2	2		2			2	
31	VEHICLE DISPATCHING RULES	3	3		3			3		
32	VEHICLE SELECTION	4	4		4			4		
33	EMPTY VEHICLE MANAGEMENT	4	4			4		1	3	
34	MULTIPLE LOADS	3	3		1	2		1	2	
35	VARYING PART TYPES	3	3		1	2		2	1	
36	PRIORITIES AT INTERFACE POINTS	4	4		4			4		
37	PARAMETER STATUS	4	4		3	1			4	

SECTION B: AUTOMATED STORAGE/RETRIEVAL SYSTEMS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	STORAGE RACK CONFIGURATION	4	4		1	2	1	2	1	1
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	4	4			3	1	1	2	1
3	INDIVIDUAL STORAGE DIMENSIONS	4	4			3	1		3	1
4	VARYING STORAGE DIMENSIONS	4	4			3	1		3	1
5	MULTIPLE LOADS	4	3	1	1	2		2	1	
6	CAPACITY SPECIFICATION	4	3	1	1	2		1	2	
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	4	2	2		2			2	
8	STORAGE POLICIES	4	3	1		2	1		2	1
9	STORAGE LEVEL DETERMINATION	4	3	1		2	1	1	1	1
10	STORAGE RACKS ON BOTH SIDES	4	3	1		3		1	2	
11	RETRIEVAL POLICIES	3	3		1	2		1	2	
12	PART LOCATING CAPABILITIES	4	3	1		2	1		2	1
13	VERTICAL SPEED (hoisting)	4	4		2	2		3	1	
14	HORIZONTAL SPEED (cruising)	4	4		2	2		3	1	
15	ACCELERATION	4	4		1	3		1	3	
16	DECELERATION	4	4		1	3		1	3	
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	4	4			2	1		3	
18	VARYING INPUT/OUTPUT LOCATIONS	2	2			1	1		1	1
19	INPUT/OUTPUT PICK UP	3	3			3		1	1	
20	STORAGE PICK UP	3	3			3		1	1	
21	INPUT/OUTPUT DEPOSIT	3	3			3		1	1	
22	STORAGE DEPOSIT	3	3			3		1	1	
23	DWELL POINT STRATEGIES	3	2	1		2		1	1	
24	SINGLE COMMAND RETRIEVAL SEQUENCING	3	2	1		2			2	
25	DUAL COMMAND RETRIEVAL SEQUENCING	3	2	1		2			2	
26	CORRECTIVE MAINTENANCE	3	3			3		1	1	
27	PREVENTIVE MAINTENANCE	3	3			3		1	1	
28	DUAL SHUTTLES	3	2	1		2			2	
29	MULTIPLE S/R MACHINES	2	2			2			2	
30	TIER ASSIGNED S/R MACHINES	2	2			2		1	1	
31	AISLE TRANSFER CAR	2	2			2		1	1	
32	ZONING	2	2			1	1	1		1

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SECTION C: BELT/ROLLER CONVEYORS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	CONVEYOR GEOMETRY	4	4		4			2		
2	DIRECTION OF TRAVEL	4	4		3	1		2		
3	CONVEYOR SECTIONS	4	4		4			1	1	
4	SPEED OF SECTIONS	4	3	1	3			2		
5	LOAD SIZE	4	4		3			2		
6	SPACING OF LOADS	4	3	1	3			2		
7	SORTATION CAPABILITIES	4	3	1	1	2		2	1	
8	ONBOARD OPERATIONS	4	3	1		3		1	2	
9	TRANSFER FROM SECTIONS	3	3		1	2		1	1	
10	TRANSFER OFF CONVEYOR	4	4		1	3		2		
11	RIGHT ANGLE TRANSFER	4	4			4		1	2	
12	LOADING TIME	4	4		1	3		2		
13	UNLOADING TIME	4	4		1	3		2		
14	CONVEYOR CAPACITY	4	4		4			1	1	
15	BI-DIRECTIONAL TRANSFER	4	2	2	1	1				1
16	TWO WAY BELT CONVEYOR	4	4		2	1		1	1	
17	LOADING/UNLOADING POINTS	4	4		3			2		
18	MULTIPLE ENTRY/EXIT POINTS	4	3	1	3			2		
19	SIMULTANEOUS ENTRIES/EXITS	4	3	1	2	1		2	1	
20	ACCUMULATION	3	3		3			2		
21	TRANSPORT	4	4		3			2		
22	LOADS WITH UNEQUAL LENGTHS	4	3	1	3			2		
23	SENSORS	4	3	1		3		1	2	
24	PREVENTIVE MAINTENANCE	4	3	1		3		2	1	
25	CORRECTIVE MAINTENANCE	4	3	1		3		2	1	

SECTION D: GANTRY CRANES		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	BRIDGE SPEED	3	3		2	1		3		
2	HOIST SPEED	3	3		1	2		3		
3	PICKING DEVICE	3	3		1	2		3		
4	ACCELERATION (bridge & hoist)	3	3			3		1	2	
5	DECELERATION (bridge & hoist)	3	3			3		1	2	
6	PICK UP TIME	3	3		1	2		3		
7	DEPOSIT TIME	3	3		1	2		3		
8	POSITIONING	3	3		1	2		2	1	
9	JOB SEARCH PRIORITY	3	3		1	2		3		
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	3	3			3			3	
11	MULTIPLE CRANES ON RUNWAY	3	3			3			3	
12	MULTIPLE CRANES IN DIFFERENT BAYS	3	3		1	2		2	1	
13	INTERFERENCE	3	3			3		1	1	1
14	IDLE CRANE MANAGEMENT RULES	3	3			3		1	2	
15	CORRECTIVE MAINTENANCE	3	3			3		1	2	
16	PREVENTIVE MAINTENANCE	3	3			3		1	2	
17	TRANSPORT OF MULTIPLE LOADS	3	3		1	2		1	2	

SECTION E: INDUSTRIAL FORK TRUCKS		SAMPLE SIZE	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	4	4		4			4		
2	TRAVEL TIME	4	4		4			4		
3	PICK UP TIME	4	4		2	2		4		
4	DEPOSIT TIME	4	4		2	2		4		
5	HOME POSITION	4	4		1	3		2	2	
6	ACCELERATION	4	3	1	2	1		2	1	
7	DECELERATION	4	3	1	2	1		2	1	
8	LIFT SPECIFICATIONS	4	3	1		3			3	
9	JOB SEARCH PRIORITY	4	3	1	2	1		3		
10	BATTERY RECHARGING	4	4			4		2	2	
11	DISTANCE/TIME TRAVELED	3	3		3			3		
12	VARYING SPEEDS	4	3	1	3			3		
13	COLLISION AVOIDANCE	4	2	2		2			2	
14	PATH	4	3	1	2	1		2	1	
15	PASSING	4	2	2		2			2	
16	ROUTING FROM PRESENT LOCATION	4	4		3			3		
17	VEHICLE SELECTION	4	4		4			4		
18	CORRECTIVE MAINTENANCE	3	3			3		1	2	
19	PREVENTIVE MAINTENANCE	3	3			3		1	2	
20	LOAD AND FIXTURE SEPARATION	4	3	1		3		1	2	

SECTION F: INDUSTRIAL ROBOTS		SAMPLE SZ	Modeling Capability: Yes	Modeling Capability: No	Modeling Method: DIRECT	Modeling Method: INDIRECT	Modeling Method: EXTERNAL	Level of Difficulty: EASY	Level of Difficulty: MODERATE	Level of Difficulty: DIFFICULT
1	HOME POSITION	4	2	2	1	1			1	
2	MULTIPLE DEGREES OF FREEDOM	4	2	2		2				2
3	VERTICAL TRAVERSE	4	2	2		2			1	1
4	RADIAL TRAVERSE	4	2	2		2			1	1
5	ROTATIONAL TRAVERSE	4	2	2		2			1	1
6	TRAVEL TIME	4	4		1	3		2		1
7	SPEED	4	4		2	2		3		1
8	SPEED FOR ALL DEGREES OF FREEDOM	4	2	2		2				2
9	PATH LOGIC	4	2	2		2			1	1
10	MULTIPLE TASKS PERFORMED	4	3	1	1	2		2	1	
11	JOB SEARCH PRIORITIES	4	4		1	3		4		
12	SEQUENCE VARIATION	3	3		1	2		3		
13	PICK AND PLACE	2	2			2		2		
14	MULTIPLE GRASPING ATTEMPTS	4	3	1		3			3	
15	SENSORS	4	3	1		3		1	2	
16	SHARED WORK ENVELOPE	4	2	2		2			1	1
17	MULTIPLE SERVICE STATIONS	3	2	1		2		1	1	
18	CORRECTIVE MAINTENANCE	3	3			3		1	2	
19	PREVENTIVE MAINTENANCE	3	3			3		1	2	

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	SECTION A: AUTOMATED GUIDED VEHICLE SYSTEMS	SAMPLE SZ	Modeling Capability: Yes	Modeling Capability: No	Modeling Method: DIRECT	Modeling Method: INDIRECT	Modeling Method: EXTERNAL	Level of Difficulty: EASY	Level of Difficulty: MODERATE	Level of Difficulty: DIFFICULT
1	SPEED	3	3		3			3		
2	TRAVEL TIME	3	3		2	1		3		
3	PICKUP TIME	3	3		1	2		3		
4	DEPOSIT TIME	3	3		2	1		3		
5	HOME POSITION	3	3		3			3		
6	ACCELERATION	3	3		2	1		2	1	
7	DECELERATION	3	3		2	1		2	1	
8	EMPTY VEHICLE TRAVEL SPEED	3	3		3			3		
9	REDIRECTION OF IN-TRANSIT VEHICLES	3	2	1	1		1	1	1	
10	JOB SEARCH PRIORITIES	3	3		3			3		
11	MAPPING (excluding shortest route)	3	3		1		2	1	2	
12	SHORTEST ROUTE MAPPING	3	3		3			2		
13	BATTERY RECHARGING	3	2	1		1	1		2	
14	GUIDEPATH LAYOUT	3	3		3			3		
15	SPURS	3	3		3			3		
16	COLLISION AVOIDANCE	3	3		3			3		
17	ZONE CONTROL	3	3		1	1	1	1	1	1
18	CONTROL SYSTEM	3	3		1		2	1	2	
19	VEHICLE FLEET	3	3		3			3		
20	HOMOGENOUS CHARACTERISTICS OF FLEET	3	3		3			3		
21	MULTIPLE FLEETS	3	3		3			3		
22	VEHICLE LIMITATIONS ON GUIDEPATH	3	3		3			3		
23	ONBOARD OPERATIONS	3	3		1	2		2	1	
24	PRESENT LOCATION VEHICLE ROUTING	3	3		2		1	1	2	
25	CORRECTIVE MAINTENANCE	3	3		1	1	1	2	1	
26	PREVENTIVE MAINTENANCE	3	3		1	2		2	1	
27	BI-DIRECTIONAL TRAVEL	3	3		3			3		
28	PASSING	3	3		1		2		3	
29	REROUTING	3	3		1		2		3	
30	PATH SEGMENT DOWNTIME	3	2	1			2		2	
31	VEHICLE DISPATCHING RULES	3	3		3			3		
32	VEHICLE SELECTION	3	3		3			3		
33	EMPTY VEHICLE MANAGEMENT	3	3		3			3		
34	MULTIPLE LOADS	3	2	1		1	1	1		1
35	VARYING PART TYPES	3	3		2		1	2		1
36	PRIORITIES AT INTERFACE POINTS	3	3		2		1	2	1	
37	PARAMETER STATUS	3	3			2	1		1	1

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SECTION B: AUTOMATED STORAGE/RETRIEVAL SYSTEMS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	STORAGE RACK CONFIGURATION	2	2		2			2		
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	2	2		2			2		
3	INDIVIDUAL STORAGE DIMENSIONS	2	2		1		1	1	1	
4	VARYING STORAGE DIMENSIONS	2	2		1		1	1	1	
5	MULTIPLE LOADS	2	2		1		1	1	1	
6	CAPACITY SPECIFICATION	2	2		2			2		
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	2	2			2			2	
8	STORAGE POLICIES	2	2		1		1	1	1	
9	STORAGE LEVEL DETERMINATION	2	2			1	1		2	
10	STORAGE RACKS ON BOTH SIDES	2	2		1		1	1	1	
11	RETRIEVAL POLICIES	2	2			1	1		1	
12	PART LOCATING CAPABILITIES	2	2		1		1	1	1	
13	VERTICAL SPEED (hoisting)	2	2		2			2		
14	HORIZONTAL SPEED (cruising)	2	2		2			2		
15	ACCELERATION	2	2		2			2		
16	DECELERATION	2	2		2			2		
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	2	2		2			2		
18	VARYING INPUT/OUTPUT LOCATIONS	2	2		2			2		
19	INPUT/OUTPUT PICK UP	2	2			2		2		
20	STORAGE PICK UP	2	2			2		2		
21	INPUT/OUTPUT DEPOSIT	2	2			2		2		
22	STORAGE DEPOSIT	2	2			2		2		
23	DWELL POINT STRATEGIES	2	1	1		1		1		
24	SINGLE COMMAND RETRIEVAL SEQUENCING	2	2		1	1		1	1	
25	DUAL COMMAND RETRIEVAL SEQUENCING	2	2		1	1		1	1	
26	CORRECTIVE MAINTENANCE	2	1	1		1		1		
27	PREVENTIVE MAINTENANCE	2	2			1	1	1	1	
28	DUAL SHUTTLES	2		2						
29	MULTIPLE S/R MACHINES	2	2		2			2		
30	TIER ASSIGNED S/R MACHINES	2	2		2			2		
31	AISLE TRANSFER CAR	2	1	1		1			1	
32	ZONING	2	2		2			2		

SECTION C: BELT/ROLLER CONVEYORS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	CONVEYOR GEOMETRY	3	3		1	2		3		
2	DIRECTION OF TRAVEL	3	3		1	2		3		
3	CONVEYOR SECTIONS	3	3		1	2		3		
4	SPEED OF SECTIONS	3	3		1	2		3		
5	LOAD SIZE	3	2	1	1	1		2		
6	SPACING OF LOADS	3	2	1	1	1		2		
7	SORTATION CAPABILITIES	3	2	1	1	1		2		
8	ONBOARD OPERATIONS	3	3		1	1		1	1	
9	TRANSFER FROM SECTIONS	3	3		1	2		3		
10	TRANSFER OFF CONVEYOR	3	3		1	2		3		
11	RIGHT ANGLE TRANSFER	3	3		1	2		2	1	
12	LOADING TIME	3	3		1	2		3		
13	UNLOADING TIME	3	3		1	2		3		
14	CONVEYOR CAPACITY	3	3		1	2		3		
15	BI-DIRECTIONAL TRANSFER	3	3			3		1	2	
16	TWO WAY BELT CONVEYOR	3	3			3			3	
17	LOADING/UNLOADING POINTS	3	3		1	2		3		
18	MULTIPLE ENTRY/EXIT POINTS	3	3		1	2		3		
19	SIMULTANEOUS ENTRIES/EXITS	3	3		1	2		3		
20	ACCUMULATION	3	3		1	2		3		
21	TRANSPORT	3	3		1	2		1	2	
22	LOADS WITH UNEQUAL LENGTHS	3	2	1		2		1	1	
23	SENSORS	3	3		1	2		2	1	
24	PREVENTIVE MAINTENANCE	3	3		1	2		2	1	
25	CORRECTIVE MAINTENANCE	3	3		1	2		2	1	

SECTION D: GANTRY CRANES		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	BRIDGE SPEED	3	3		2	1		3		
2	HOIST SPEED	3	2	1	2			2		
3	PICKING DEVICE	3	2	1		2		2		
4	ACCELERATION (bridge & hoist)	3	2	1	2			2		
5	DECELERATION (bridge & hoist)	3	2	1	2			2		
6	PICK UP TIME	3	3			3		3		
7	DEPOSIT TIME	3	3			3		3		
8	POSITIONING	3	3		2	1		3		
9	JOB SEARCH PRIORITY	3	3		3			3		
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	3	2	1	2			2		
11	MULTIPLE CRANES ON RUNWAY	3	3		3			3		
12	MULTIPLE CRANES IN DIFFERENT BAYS	3	3		3			2	1	
13	INTERFERENCE	3	3		3			3		
14	IDLE CRANE MANAGEMENT RULES	3	2	1	1		1	1	1	
15	CORRECTIVE MAINTENANCE	3	2	1	1	1		1	1	
16	PREVENTIVE MAINTENANCE	3	3		1	2		2	1	
17	TRANSPORT OF MULTIPLE LOADS	3	1	2	1					1

#	SECTION E: INDUSTRIAL FORK TRUCKS	SAMPLE SZ	Modeling Capability: Yes	No	Modeling Method: DIRECT	INDIRECT	EXTERNAL	Level of Difficulty: EASY	MODERATE	DIFFICULT
1	SPEED	3	3		1	2		3		
2	TRAVEL TIME	3	3		1	2		3		
3	PICK UP TIME	3	3		1	2		3		
4	DEPOSIT TIME	3	3		1	2		3		
5	HOME POSITION	3	2	1	1	1	1	2	1	
6	ACCELERATION	3		3						
7	DECELERATION	3		3						
8	LIFT SPECIFICATIONS	4	2	2		1			1	
9	JOB SEARCH PRIORITY	3	3		1	2		2	1	
10	BATTERY RECHARGING	3	2	1		2			2	
11	DISTANCE/TIME TRAVELED	3	3		1	1	1	2	1	
12	VARYING SPEEDS	3	3		1	1		2	1	
13	COLLISION AVOIDANCE	3	2	1	1		1	1		1
14	PATH	3	3		1	1	1	1	2	
15	PASSING	3	3		1	1	1	1	2	
16	ROUTING FROM PRESENT LOCATION	3	3		1	1	1	1	2	
17	VEHICLE SELECTION	3	3		1	2		2	1	
18	CORRECTIVE MAINTENANCE	3	3		1	2		2	1	
19	PREVENTIVE MAINTENANCE	3	3		1	2		2	1	
20	LOAD AND FIXTURE SEPARATION	3	3		1	2		1	2	

SECTION F: INDUSTRIAL ROBOTS		SAMPLE SZ	Modeling Capability		Modeling Method			Level of Difficulty		
			Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	HOME POSITION	3	2	1		2		1	1	
2	MULTIPLE DEGREES OF FREEDOM	3	2	1		1	1		1	1
3	VERTICAL TRAVERSE	3	2	1		1	1		1	1
4	RADIAL TRAVERSE	3	2	1		1	1		1	1
5	ROTATIONAL TRAVERSE	3	2	1		1	1		1	1
6	TRAVEL TIME	3	2	1		2		1	1	
7	SPEED	3	2	1		2		1	1	
8	SPEED FOR ALL DEGREES OF FREEDOM	3	2	1		1	1		2	
9	PATH LOGIC	3	1	2		1			1	
10	MULTIPLE TASKS PERFORMED	3	2	1		1	1	1	1	
11	JOB SEARCH PRIORITIES	3	2	1	1	1		1	1	
12	SEQUENCE VARIATION	3	2	1		2			2	
13	PICK AND PLACE	3	2	1		1	1	1	1	
14	MULTIPLE GRASPING ATTEMPTS	3	2	1		1	1		2	
15	SENSORS	3	2	1		2		1	1	
16	SHARED WORK ENVELOPE	3	2	1		2		1	1	
17	MULTIPLE SERVICE STATIONS	3	2	1		2		1	1	
18	CORRECTIVE MAINTENANCE	3	3		1	2		2	1	
19	PREVENTIVE MAINTENANCE	3	3		1	2		2	1	

APPENDIX C: PERCENTAGE TABLES OF SURVEY RESPONSES

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SECTION A: AUTOMATED GUIDED VEHICLE SYSTEMS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	100%	0%	0%	100%	0%	50%	50%	0%
2	TRAVEL TIME	100%	0%	100%	0%	0%	100%	0%	0%
3	PICKUP TIME	100%	0%	100%	0%	0%	100%	0%	0%
4	DEPOSIT TIME	100%	0%	100%	0%	0%	100%	0%	0%
5	HOME POSITION	100%	0%	0%	100%	0%	50%	50%	0%
6	ACCELERATION	50%	50%	0%	50%	0%	50%	0%	0%
7	DECELERATION	50%	50%	0%	50%	0%	50%	0%	0%
8	EMPTY VEHICLE TRAVEL SPEED	100%	0%	0%	100%	0%	50%	0%	50%
9	REDIRECTION OF IN-TRANSIT VEHICLES	100%	0%	100%	0%	0%	100%	0%	0%
10	JOB SEARCH PRIORITIES	100%	0%	100%	0%	0%	100%	0%	0%
11	MAPPING (excluding shortest route)	100%	0%	100%	0%	0%	100%	0%	0%
12	SHORTEST ROUTE MAPPING	100%	0%	100%	0%	0%	100%	0%	0%
13	BATTERY RECHARGING	100%	0%	100%	0%	0%	100%	0%	0%
14	GUIDEPATH LAYOUT	100%	0%	50%	50%	0%	50%	0%	50%
15	SPURS	50%	50%	50%	0%	0%	50%	0%	0%
16	COLLISION AVOIDANCE	100%	0%	0%	100%	0%	0%	0%	100%
17	ZONE CONTROL	100%	0%	0%	100%	0%	0%	50%	50%
18	CONTROL SYSTEM	100%	0%	0%	100%	0%	0%	0%	100%
19	VEHICLE FLEET	100%	0%	100%	0%	0%	100%	0%	0%
20	HOMOGENOUS CHARACTERISTICS OF FLEET	50%	50%	50%	0%	0%	50%	0%	0%
21	MULTIPLE FLEETS	50%	50%	50%	0%	0%	50%	0%	0%
22	VEHICLE LIMITATIONS ON GUIDEPATH	100%	0%	50%	50%	0%	100%	0%	0%
23	ONBOARD OPERATIONS	100%	0%	100%	0%	0%	100%	0%	0%
24	PRESENT LOCATION VEHICLE ROUTING	100%	0%	0%	100%	0%	0%	0%	100%
25	CORRECTIVE MAINTENANCE	100%	0%	100%	0%	0%	50%	50%	0%
26	PREVENTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%
27	BI-DIRECTIONAL TRAVEL	50%	50%	0%	50%	0%	50%	0%	0%
28	PASSING	50%	50%	0%	50%	0%	0%	50%	0%
29	REROUTING	100%	0%	50%	50%	0%	0%	100%	0%
30	PATH SEGMENT DOWNTIME	100%	0%	100%	0%	0%	100%	0%	0%
31	VEHICLE DISPATCHING RULES	100%	0%	50%	50%	0%	0%	50%	50%
32	VEHICLE SELECTION	50%	50%	0%	50%	0%	0%	50%	0%
33	EMPTY VEHICLE MANAGEMENT	100%	0%	50%	50%	0%	50%	50%	0%
34	MULTIPLE LOADS	100%	0%	50%	50%	0%	100%	0%	0%
35	VARYING PART TYPES	100%	0%	100%	0%	0%	100%	0%	0%
36	PRIORITIES AT INTERFACE POINTS	50%	50%	0%	50%	0%	0%	50%	0%
37	PARAMETER STATUS	50%	50%	0%	50%	0%	0%	0%	50%

SECTION B: AUTOMATED STORAGE/RETRIEVAL SYSTEMS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	STORAGE RACK CONFIGURATION	100%	0%	50%	50%	0%	50%	0%	50%
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	100%	0%	100%	0%	0%	100%	0%	0%
3	INDIVIDUAL STORAGE DIMENSIONS	100%	0%	50%	50%	0%	50%	0%	50%
4	VARYING STORAGE DIMENSIONS	100%	0%	50%	50%	0%	50%	0%	50%
5	MULTIPLE LOADS	100%	0%	0%	100%	0%	0%	50%	50%
6	CAPACITY SPECIFICATION	100%	0%	50%	50%	0%	50%	0%	50%
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	50%	50%	0%	50%	0%	0%	50%	0%
8	STORAGE POLICIES	50%	50%	0%	50%	0%	0%	50%	0%
9	STORAGE LEVEL DETERMINATION	100%	0%	0%	100%	0%	50%	0%	50%
10	STORAGE RACKS ON BOTH SIDES	100%	0%	0%	100%	0%	0%	50%	50%
11	RETRIEVAL POLICIES	50%	50%	50%	0%	0%	50%	0%	0%
12	PART LOCATING CAPABILITIES	100%	0%	0%	100%	0%	50%	0%	50%
13	VERTICAL SPEED (hoisting)	100%	0%	0%	100%	0%	0%	100%	0%
14	HORIZONTAL SPEED (cruising)	100%	0%	0%	100%	0%	50%	50%	0%
15	ACCELERATION	50%	50%	0%	50%	0%	50%	0%	0%
16	DECELERATION	50%	50%	0%	50%	0%	50%	0%	0%
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	50%	50%	0%	50%	0%	0%	50%	0%
18	VARYING INPUT/OUTPUT LOCATIONS	100%	0%	0%	100%	0%	100%	0%	0%
19	INPUT/OUTPUT PICK UP	100%	0%	100%	0%	0%	100%	0%	0%
20	STORAGE PICK UP	100%	0%	100%	0%	0%	100%	0%	0%
21	INPUT/OUTPUT DEPOSIT	100%	0%	100%	0%	0%	100%	0%	0%
22	STORAGE DEPOSIT	100%	0%	100%	0%	0%	100%	0%	0%
23	DWELL POINT STRATEGIES	100%	0%	0%	100%	0%	0%	0%	100%
24	SINGLE COMMAND RETRIEVAL SEQUENCING	100%	0%	0%	100%	0%	0%	100%	0%
25	DUAL COMMAND RETRIEVAL SEQUENCING	100%	0%	0%	100%	0%	50%	0%	50%
26	CORRECTIVE MAINTENANCE	100%	0%	100%	0%	0%	50%	50%	0%
27	PREVENTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%
28	DUAL SHUTTLES	100%	0%	0%	100%	0%	0%	50%	50%
29	MULTIPLE S/R MACHINES	50%	50%	0%	50%	0%	0%	0%	50%
30	TIER ASSIGNED S/R MACHINES	100%	0%	50%	50%	0%	0%	50%	50%
31	AISLE TRANSFER CAR	100%	0%	0%	100%	0%	0%	50%	50%
32	ZONING	100%	0%	0%	100%	0%	0%	50%	50%

SECTION C: BELT/ROLLER CONVEYORS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	CONVEYOR GEOMETRY	100%	0%	100%	0%	0%	100%	0%	0%
2	DIRECTION OF TRAVEL	100%	0%	100%	0%	0%	100%	0%	0%
3	CONVEYOR SECTIONS	100%	0%	100%	0%	0%	50%	50%	0%
4	SPEED OF SECTIONS	100%	0%	0%	100%	0%	50%	50%	0%
5	LOAD SIZE	100%	0%	0%	100%	0%	50%	0%	50%
6	SPACING OF LOADS	50%	50%	0%	50%	0%	0%	50%	0%
7	SORTATION CAPABILITIES	100%	0%	100%	0%	0%	100%	0%	0%
8	ONBOARD OPERATIONS	50%	50%	50%	0%	0%	50%	0%	0%
9	TRANSFER FROM SECTIONS	100%	0%	100%	0%	0%	100%	0%	0%
10	TRANSFER OFF CONVEYOR	100%	0%	100%	0%	0%	100%	0%	0%
11	RIGHT ANGLE TRANSFER	100%	0%	100%	0%	0%	100%	0%	0%
12	LOADING TIME	100%	0%	100%	0%	0%	100%	0%	0%
13	UNLOADING TIME	100%	0%	100%	0%	0%	100%	0%	0%
14	CONVEYOR CAPACITY	100%	0%	100%	0%	0%	50%	50%	0%
15	BI-DIRECTIONAL TRANSFER	100%	0%	0%	100%	0%	0%	100%	0%
16	TWO WAY BELT CONVEYOR	100%	0%	50%	50%	0%	0%	100%	0%
17	LOADING/UNLOADING POINTS	100%	0%	100%	0%	0%	50%	0%	50%
18	MULTIPLE ENTRY/EXIT POINTS	100%	0%	100%	0%	0%	50%	0%	50%
19	SIMULTANEOUS ENTRIES/EXITS	100%	0%	100%	0%	0%	0%	50%	50%
20	ACCUMULATION	100%	0%	100%	0%	0%	100%	0%	0%
21	TRANSPORT	50%	50%	50%	0%	0%	50%	0%	0%
22	LOADS WITH UNEQUAL LENGTHS	100%	0%	0%	100%	0%	0%	50%	50%
23	SENSORS	100%	0%	100%	0%	0%	100%	0%	0%
24	PREVENTIVE MAINTENANCE	100%	0%	100%	0%	0%	50%	50%	0%
25	CORRECTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%

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SECTION D: GANTRY CRANES		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	BRIDGE SPEED	100%	0%	0%	100%	0%	50%	0%	50%
2	HOIST SPEED	100%	0%	0%	100%	0%	50%	0%	50%
3	PICKING DEVICE	50%	50%	0%	50%	0%	50%	0%	0%
4	ACCELERATION (bridge & hoist)	50%	50%	0%	50%	0%	0%	50%	0%
5	DECELERATION (bridge & hoist)	50%	50%	0%	50%	0%	0%	50%	0%
6	PICK UP TIME	100%	0%	100%	0%	0%	100%	0%	0%
7	DEPOSIT TIME	100%	0%	100%	0%	0%	100%	0%	0%
8	POSITIONING	50%	50%	0%	50%	0%	0%	50%	0%
9	JOB SEARCH PRIORITY	100%	0%	100%	0%	0%	100%	0%	0%
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	100%	0%	0%	100%	0%	0%	50%	50%
11	MULTIPLE CRANES ON RUNWAY	100%	0%	50%	50%	0%	0%	50%	50%
12	MULTIPLE CRANES IN DIFFERENT BAYS	100%	0%	100%	0%	0%	50%	50%	0%
13	INTERFERENCE	100%	0%	0%	100%	0%	0%	50%	50%
14	IDLE CRANE MANAGEMENT RULES	100%	0%	50%	50%	0%	50%	50%	0%
15	CORRECTIVE MAINTENANCE	100%	0%	100%	0%	0%	50%	50%	0%
16	PREVENTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%
17	TRANSPORT OF MULTIPLE LOADS	100%	0%	0%	100%	0%	0%	100%	0%

SECTION E: INDUSTRIAL FORK TRUCKS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	100%	0%	0%	100%	0%	0%	50%	50%
2	TRAVEL TIME	100%	0%	100%	0%	0%	100%	0%	0%
3	PICK UP TIME	100%	0%	100%	0%	0%	100%	0%	0%
4	DEPOSIT TIME	100%	0%	100%	0%	0%	100%	0%	0%
5	HOME POSITION	100%	0%	100%	0%	0%	100%	0%	0%
6	ACCELERATION	50%	50%	0%	50%	0%	0%	50%	0%
7	DECELERATION	50%	50%	0%	50%	0%	0%	50%	0%
8	LIFT SPECIFICATIONS	100%	0%	50%	50%	0%	50%	50%	0%
9	JOB SEARCH PRIORITY	100%	0%	100%	0%	0%	100%	0%	0%
10	BATTERY RECHARGING	100%	0%	50%	50%	0%	100%	0%	0%
11	DISTANCE/TIME TRAVELED	100%	0%	50%	50%	0%	50%	50%	0%
12	VARYING SPEEDS	100%	0%	0%	100%	0%	50%	50%	0%
13	COLLISION AVOIDANCE	100%	0%	0%	100%	0%	0%	0%	100%
14	PATH	50%	50%	0%	50%	0%	0%	50%	0%
15	PASSING	50%	50%	0%	50%	0%	0%	50%	0%
16	ROUTING FROM PRESENT LOCATION	50%	50%	0%	50%	0%	0%	50%	0%
17	VEHICLE SELECTION	50%	50%	0%	50%	0%	0%	50%	0%
18	CORRECTIVE MAINTENANCE	100%	0%	100%	0%	0%	50%	50%	0%
19	PREVENTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%
20	LOAD AND FIXTURE SEPARATION	100%	0%	100%	0%	0%	100%	0%	0%

SECTION F: INDUSTRIAL ROBOTS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	HOME POSITION	100%	0%	100%	0%	0%	100%	0%	0%
2	MULTIPLE DEGREES OF FREEDOM	100%	0%	0%	100%	0%	0%	100%	0%
3	VERTICAL TRAVERSE	100%	0%	0%	100%	0%	100%	0%	0%
4	RADIAL TRAVERSE	100%	0%	0%	100%	0%	100%	0%	0%
5	ROTATIONAL TRAVERSE	100%	0%	0%	100%	0%	100%	0%	0%
6	TRAVEL TIME	100%	0%	0%	100%	0%	100%	0%	0%
7	SPEED	100%	0%	0%	100%	0%	100%	0%	0%
8	SPEED FOR ALL DEGREES OF FREEDOM	100%	0%	0%	100%	0%	100%	0%	0%
9	PATH LOGIC	100%	0%	0%	100%	0%	0%	100%	0%
10	MULTIPLE TASKS PERFORMED	100%	0%	0%	100%	0%	0%	100%	0%
11	JOB SEARCH PRIORITIES	100%	0%	100%	0%	0%	100%	0%	0%
12	SEQUENCE VARIATION	100%	0%	0%	100%	0%	0%	100%	0%
13	PICK AND PLACE	100%	0%	0%	100%	0%	100%	0%	0%
14	MULTIPLE GRASPING ATTEMPTS	100%	0%	0%	100%	0%	100%	0%	0%
15	SENSORS	100%	0%	0%	100%	0%	0%	100%	0%
16	SHARED WORK ENVELOPE	100%	0%	0%	100%	0%	0%	0%	100%
17	MULTIPLE SERVICE STATIONS	100%	0%	0%	100%	0%	0%	100%	0%
18	CORRECTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%
19	PREVENTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%

SECTION A: AUTOMATED GUIDED VEHICLE SYSTEMS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	100%	0%	100%	0%	0%	100%	0%	0%
2	TRAVEL TIME	100%	0%	100%	0%	0%	100%	0%	0%
3	PICKUP TIME	100%	0%	100%	0%	0%	100%	0%	0%
4	DEPOSIT TIME	100%	0%	100%	0%	0%	100%	0%	0%
5	HOME POSITION	100%	0%	100%	0%	0%	100%	0%	0%
6	ACCELERATION	100%	0%	100%	0%	0%	100%	0%	0%
7	DECELERATION	100%	0%	100%	0%	0%	100%	0%	0%
8	EMPTY VEHICLE TRAVEL SPEED	50%	50%	50%	0%	0%	50%	0%	0%
9	REDIRECTION OF IN-TRANSIT VEHICLES	0%	100%	0%	100%	0%	0%	100%	0%
10	JOB SEARCH PRIORITIES	100%	0%	100%	0%	0%	33%	33%	0%
11	MAPPING (excluding shortest route)	100%	0%	67%	0%	0%	33%	0%	33%
12	SHORTEST ROUTE MAPPING	100%	0%	50%	0%	0%	50%	0%	0%
13	BATTERY RECHARGING	100%	0%	0%	100%	0%	100%	0%	0%
14	GUIDEPATH LAYOUT	100%	0%	67%	0%	0%	33%	33%	0%
15	SPURS	100%	0%	33%	33%	0%	33%	33%	0%
16	COLLISION AVOIDANCE	100%	0%	50%	50%	0%	50%	50%	0%
17	ZONE CONTROL	100%	0%	100%	0%	0%	50%	50%	0%
18	CONTROL SYSTEM	100%	0%	50%	50%	0%	50%	0%	50%
19	VEHICLE FLEET	100%	0%	100%	0%	0%	100%	0%	0%
20	HOMOGENOUS CHARACTERISTICS OF FLEET	100%	0%	100%	0%	0%	100%	0%	0%
21	MULTIPLE FLEETS	100%	0%	100%	0%	0%	100%	0%	0%
22	VEHICLE LIMITATIONS ON GUIDEPATH	100%	0%	50%	50%	0%	50%	50%	0%
23	ONBOARD OPERATIONS	100%	0%	33%	0%	0%	33%	0%	0%
24	PRESENT LOCATION VEHICLE ROUTING	50%	50%	0%	50%	0%	0%	50%	0%
25	CORRECTIVE MAINTENANCE	100%	0%	67%	33%	0%	67%	0%	0%
26	PREVENTIVE MAINTENANCE	100%	0%	67%	33%	0%	67%	0%	0%
27	BI-DIRECTIONAL TRAVEL	100%	0%	100%	0%	0%	100%	0%	0%
28	PASSING	50%	50%	50%	0%	0%	50%	0%	0%
29	REROUTING	100%	0%	0%	100%	0%	0%	50%	50%
30	PATH SEGMENT DOWNTIME	100%	0%	0%	100%	0%	0%	50%	50%
31	VEHICLE DISPATCHING RULES	100%	0%	100%	0%	0%	100%	0%	0%
32	VEHICLE SELECTION	100%	0%	50%	50%	0%	50%	50%	0%
33	EMPTY VEHICLE MANAGEMENT	100%	0%	50%	0%	0%	50%	0%	0%
34	MULTIPLE LOADS	50%	50%	50%	0%	0%	0%	50%	0%
35	VARYING PART TYPES	100%	0%	50%	50%	0%	50%	50%	0%
36	PRIORITIES AT INTERFACE POINTS	100%	0%	0%	100%	0%	0%	100%	0%
37	PARAMETER STATUS	50%	50%	0%	50%	0%	0%	50%	0%

SECTION B: AUTOMATED STORAGE/RETRIEVAL SYSTEMS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	STORAGE RACK CONFIGURATION	100%	0%	0%	100%	0%	0%	50%	50%
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	100%	0%	0%	100%	0%	0%	50%	50%
3	INDIVIDUAL STORAGE DIMENSIONS	50%	50%	0%	50%	0%	0%	50%	0%
4	VARYING STORAGE DIMENSIONS	100%	0%	50%	50%	0%	50%	50%	0%
5	MULTIPLE LOADS	100%	0%	100%	0%	0%	100%	0%	0%
6	CAPACITY SPECIFICATION	100%	0%	100%	0%	0%	100%	0%	0%
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	100%	0%	0%	100%	0%	0%	50%	50%
8	STORAGE POLICIES	100%	0%	0%	100%	0%	0%	50%	50%
9	STORAGE LEVEL DETERMINATION	100%	0%	50%	50%	0%	0%	50%	50%
10	STORAGE RACKS ON BOTH SIDES	100%	0%	50%	50%	0%	50%	50%	0%
11	RETRIEVAL POLICIES	100%	0%	50%	50%	0%	50%	0%	50%
12	PART LOCATING CAPABILITIES	100%	0%	50%	50%	0%	0%	50%	50%
13	VERTICAL SPEED (hoisting)	50%	50%	50%	0%	0%	50%	0%	0%
14	HORIZONTAL SPEED (cruising)	100%	0%	100%	0%	0%	100%	0%	0%
15	ACCELERATION	100%	0%	100%	0%	0%	100%	0%	0%
16	DECELERATION	100%	0%	100%	0%	0%	100%	0%	0%
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	50%	50%	50%	0%	0%	50%	0%	0%
18	VARYING INPUT/OUTPUT LOCATIONS	100%	0%	50%	50%	0%	50%	0%	50%
19	INPUT/OUTPUT PICK UP	100%	0%	100%	0%	0%	100%	0%	0%
20	STORAGE PICK UP	100%	0%	100%	0%	0%	100%	0%	0%
21	INPUT/OUTPUT DEPOSIT	100%	0%	100%	0%	0%	100%	0%	0%
22	STORAGE DEPOSIT	100%	0%	100%	0%	0%	100%	0%	0%
23	DWELL POINT STRATEGIES	100%	0%	100%	0%	0%	100%	0%	0%
24	SINGLE COMMAND RETRIEVAL SEQUENCING	100%	0%	100%	0%	0%	100%	0%	0%
25	DUAL COMMAND RETRIEVAL SEQUENCING	100%	0%	100%	0%	0%	100%	0%	0%
26	CORRECTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%
27	PREVENTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%
28	DUAL SHUTTLES	50%	50%	0%	50%	0%	0%	0%	50%
29	MULTIPLE S/R MACHINES	100%	0%	100%	0%	0%	100%	0%	0%
30	TIER ASSIGNED S/R MACHINES	100%	0%	0%	100%	0%	0%	50%	50%
31	AISLE TRANSFER CAR	100%	0%	0%	100%	0%	0%	50%	50%
32	ZONING	100%	0%	0%	100%	0%	0%	100%	0%

SECTION C: BELT/ROLLER CONVEYORS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	CONVEYOR GEOMETRY	100%	0%	100%	0%	0%	100%	0%	0%
2	DIRECTION OF TRAVEL	100%	0%	100%	0%	0%	100%	0%	0%
3	CONVEYOR SECTIONS	100%	0%	67%	33%	0%	67%	33%	0%
4	SPEED OF SECTIONS	100%	0%	100%	0%	0%	100%	0%	0%
5	LOAD SIZE	100%	0%	100%	0%	0%	100%	0%	0%
6	SPACING OF LOADS	100%	0%	100%	0%	0%	100%	0%	0%
7	SORTATION CAPABILITIES	100%	0%	50%	50%	0%	50%	0%	50%
8	ONBOARD OPERATIONS	100%	0%	67%	33%	0%	33%	67%	0%
9	TRANSFER FROM SECTIONS	100%	0%	100%	0%	0%	67%	0%	0%
10	TRANSFER OFF CONVEYOR	100%	0%	100%	0%	0%	67%	0%	0%
11	RIGHT ANGLE TRANSFER	100%	0%	33%	33%	0%	67%	0%	0%
12	LOADING TIME	100%	0%	100%	0%	0%	100%	0%	0%
13	UNLOADING TIME	100%	0%	100%	0%	0%	100%	50%	0%
14	CONVEYOR CAPACITY	100%	0%	33%	67%	0%	67%	33%	0%
15	BI-DIRECTIONAL TRANSFER	67%	33%	67%	0%	0%	33%	0%	0%
16	TWO WAY BELT CONVEYOR	100%	0%	0%	100%	0%	0%	100%	0%
17	LOADING/UNLOADING POINTS	100%	0%	67%	33%	0%	67%	33%	0%
18	MULTIPLE ENTRY/EXIT POINTS	100%	0%	50%	50%	0%	100%	0%	0%
19	SIMULTANEOUS ENTRIES/EXITS	100%	0%	50%	50%	0%	50%	0%	50%
20	ACCUMULATION	100%	0%	100%	0%	0%	100%	0%	0%
21	TRANSPORT	100%	0%	100%	0%	0%	100%	0%	0%
22	LOADS WITH UNEQUAL LENGTHS	100%	0%	50%	50%	0%	50%	0%	50%
23	SENSORS	100%	0%	67%	33%	0%	67%	0%	33%
24	PREVENTIVE MAINTENANCE	100%	0%	67%	33%	0%	100%	0%	0%
25	CORRECTIVE MAINTENANCE	100%	0%	67%	33%	0%	100%	0%	0%

SECTION D: GANTRY CRANES		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	BRIDGE SPEED	100%	0%	100%	0%	0%	100%	0%	0%
2	HOIST SPEED	100%	0%	100%	0%	0%	100%	0%	0%
3	PICKING DEVICE	50%	50%	50%	0%	0%	50%	0%	0%
4	ACCELERATION (bridge & hoist)	100%	0%	100%	0%	0%	100%	0%	0%
5	DECELERATION (bridge & hoist)	100%	0%	100%	0%	0%	100%	0%	0%
6	PICK UP TIME	100%	0%	100%	0%	0%	100%	0%	0%
7	DEPOSIT TIME	100%	0%	100%	0%	0%	100%	0%	0%
8	POSITIONING	100%	0%	100%	0%	0%	67%	33%	0%
9	JOB SEARCH PRIORITY	100%	0%	100%	0%	0%	100%	0%	0%
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	100%	0%	50%	0%	0%	50%	0%	0%
11	MULTIPLE CRANES ON RUNWAY	100%	0%	100%	0%	0%	33%	0%	33%
12	MULTIPLE CRANES IN DIFFERENT BAYS	100%	0%	100%	0%	0%	50%	0%	0%
13	INTERFERENCE	100%	0%	50%	0%	0%	50%	0%	0%
14	IDLE CRANE MANAGEMENT RULES	100%	0%	67%	33%	0%	67%	0%	0%
15	CORRECTIVE MAINTENANCE	100%	0%	67%	33%	0%	100%	0%	0%
16	PREVENTIVE MAINTENANCE	100%	0%	67%	33%	0%	100%	0%	0%
17	TRANSPORT OF MULTIPLE LOADS	50%	50%	0%	50%	0%	0%	50%	0%

SECTION E: INDUSTRIAL FORK TRUCKS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	100%	0%	100%	0%	0%	100%	0%	0%
2	TRAVEL TIME	100%	0%	100%	0%	0%	100%	0%	0%
3	PICK UP TIME	100%	0%	100%	0%	0%	100%	0%	0%
4	DEPOSIT TIME	100%	0%	100%	0%	0%	100%	0%	0%
5	HOME POSITION	100%	0%	100%	0%	0%	100%	0%	0%
6	ACCELERATION	100%	0%	100%	0%	0%	100%	0%	0%
7	DECELERATION	100%	0%	100%	0%	0%	100%	0%	0%
8	LIFT SPECIFICATIONS	100%	0%	0%	100%	0%	0%	0%	100%
9	JOB SEARCH PRIORITY	100%	0%	100%	0%	0%	100%	0%	0%
10	BATTERY RECHARGING	100%	0%	0%	100%	0%	33%	67%	0%
11	DISTANCE/TIME TRAVELED	100%	0%	100%	0%	0%	100%	0%	0%
12	VARYING SPEEDS	50%	50%	50%	0%	0%	50%	0%	0%
13	COLLISION AVOIDANCE	100%	0%	50%	50%	0%	50%	50%	0%
14	PATH	100%	0%	100%	0%	0%	100%	0%	0%
15	PASSING	50%	50%	0%	50%	0%	0%	50%	0%
16	ROUTING FROM PRESENT LOCATION	100%	0%	0%	100%	0%	0%	100%	0%
17	VEHICLE SELECTION	100%	0%	0%	100%	0%	0%	100%	0%
18	CORRECTIVE MAINTENANCE	100%	0%	67%	33%	0%	100%	0%	0%
19	PREVENTIVE MAINTENANCE	100%	0%	67%	33%	0%	100%	0%	0%
20	LOAD AND FIXTURE SEPARATION	100%	0%	0%	100%	0%	0%	67%	33%

	SECTION F: INDUSTRIAL ROBOTS	Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	HOME POSITION	100%	0%	100%	0%	0%	100%	0%	0%
2	MULTIPLE DEGREES OF FREEDOM	50%	50%	50%	0%	0%	50%	0%	0%
3	VERTICAL TRAVERSE	50%	50%	50%	0%	0%	50%	0%	0%
4	RADIAL TRAVERSE	50%	50%	50%	0%	0%	50%	0%	0%
5	ROTATIONAL TRAVERSE	100%	0%	100%	0%	0%	100%	0%	0%
6	TRAVEL TIME	100%	0%	100%	0%	0%	100%	0%	0%
7	SPEED	100%	0%	100%	0%	0%	100%	0%	0%
8	SPEED FOR ALL DEGREES OF FREEDOM	0%	100%	0%	0%	0%	0%	0%	0%
9	PATH LOGIC	100%	0%	100%	0%	0%	50%	50%	0%
10	MULTIPLE TASKS PERFORMED	50%	50%	0%	50%	0%	0%	50%	0%
11	JOB SEARCH PRIORITIES	100%	0%	50%	50%	0%	50%	50%	0%
12	SEQUENCE VARIATION	100%	0%	0%	100%	0%	0%	100%	0%
13	PICK AND PLACE	100%	0%	100%	0%	0%	50%	50%	0%
14	MULTIPLE GRASPING ATTEMPTS	50%	50%	0%	50%	0%	0%	50%	0%
15	SENSORS	100%	0%	0%	100%	0%	0%	100%	0%
16	SHARED WORK ENVELOPE	50%	50%	0%	50%	0%	0%	50%	0%
17	MULTIPLE SERVICE STATIONS	100%	0%	100%	0%	0%	0%	100%	0%
18	CORRECTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%
19	PREVENTIVE MAINTENANCE	100%	0%	100%	0%	0%	100%	0%	0%

	SECTION A: AUTOMATED GUIDED VEHICLE SYSTEMS	Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	100%	0%	100%	0%	0%	100%	0%	0%
2	TRAVEL TIME	100%	0%	75%	25%	0%	100%	0%	0%
3	PICKUP TIME	100%	0%	50%	50%	0%	100%	0%	0%
4	DEPOSIT TIME	100%	0%	50%	50%	0%	100%	0%	0%
5	HOME POSITION	100%	0%	75%	25%	0%	75%	25%	0%
6	ACCELERATION	100%	0%	100%	0%	0%	75%	0%	0%
7	DECELERATION	100%	0%	100%	0%	0%	75%	0%	0%
8	EMPTY VEHICLE TRAVEL SPEED	75%	25%	75%	0%	0%	75%	0%	0%
9	REDIRECTION OF IN-TRANSIT VEHICLES	100%	0%	50%	50%	0%	0%	100%	0%
10	JOB SEARCH PRIORITIES	100%	0%	50%	50%	0%	75%	25%	0%
11	MAPPING (excluding shortest route)	100%	0%	100%	0%	0%	100%	0%	0%
12	SHORTEST ROUTE MAPPING	100%	0%	100%	0%	0%	75%	25%	0%
13	BATTERY RECHARGING	100%	0%	0%	100%	0%	100%	0%	0%
14	GUIDEPATH LAYOUT	100%	0%	100%	0%	0%	50%	50%	0%
15	SPURS	100%	0%	75%	25%	0%	75%	25%	0%
16	COLLISION AVOIDANCE	100%	0%	67%	33%	0%	67%	33%	0%
17	ZONE CONTROL	100%	0%	75%	25%	0%	75%	25%	0%
18	CONTROL SYSTEM	100%	0%	0%	100%	0%	33%	33%	33%
19	VEHICLE FLEET	100%	0%	100%	0%	0%	100%	0%	0%
20	HOMOGENOUS CHARACTERISTICS OF FLEET	100%	0%	100%	0%	0%	100%	0%	0%
21	MULTIPLE FLEETS	100%	0%	100%	0%	0%	100%	0%	0%
22	VEHICLE LIMITATIONS ON GUIDEPATH	100%	0%	75%	25%	0%	75%	25%	0%
23	ONBOARD OPERATIONS	75%	25%	25%	50%	0%	25%	50%	0%
24	PRESENT LOCATION VEHICLE ROUTING	100%	0%	67%	33%	0%	67%	33%	0%
25	CORRECTIVE MAINTENANCE	100%	0%	0%	75%	0%	25%	50%	25%
26	PREVENTIVE MAINTENANCE	100%	0%	50%	50%	0%	75%	25%	0%
27	BI-DIRECTIONAL TRAVEL	100%	0%	75%	25%	0%	50%	50%	0%
28	PASSING	75%	25%	25%	50%	0%	0%	75%	0%
29	REROUTING	75%	25%	0%	75%	0%	0%	75%	0%
30	PATH SEGMENT DOWNTIME	50%	50%	0%	50%	0%	0%	50%	0%
31	VEHICLE DISPATCHING RULES	100%	0%	100%	0%	0%	100%	0%	0%
32	VEHICLE SELECTION	100%	0%	100%	0%	0%	100%	0%	0%
33	EMPTY VEHICLE MANAGEMENT	100%	0%	0%	100%	0%	25%	75%	0%
34	MULTIPLE LOADS	100%	0%	33%	67%	0%	33%	67%	0%
35	VARYING PART TYPES	100%	0%	33%	67%	0%	67%	33%	0%
36	PRIORITIES AT INTERFACE POINTS	100%	0%	100%	0%	0%	100%	0%	0%
37	PARAMETER STATUS	100%	0%	75%	25%	0%	0%	100%	0%

SECTION B: AUTOMATED STORAGE/RETRIEVAL SYSTEMS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	STORAGE RACK CONFIGURATION	100%	0%	25%	50%	25%	50%	25%	25%
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	100%	0%	0%	75%	25%	25%	50%	25%
3	INDIVIDUAL STORAGE DIMENSIONS	100%	0%	0%	75%	25%	0%	75%	25%
4	VARYING STORAGE DIMENSIONS	100%	0%	0%	75%	25%	0%	75%	25%
5	MULTIPLE LOADS	75%	25%	25%	50%	0%	50%	25%	0%
6	CAPACITY SPECIFICATION	75%	25%	25%	50%	0%	25%	50%	0%
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	50%	50%	0%	50%	0%	0%	50%	0%
8	STORAGE POLICIES	75%	25%	0%	50%	25%	0%	50%	25%
9	STORAGE LEVEL DETERMINATION	75%	25%	0%	50%	25%	25%	25%	25%
10	STORAGE RACKS ON BOTH SIDES	75%	25%	0%	75%	0%	25%	50%	0%
11	RETRIEVAL POLICIES	100%	0%	33%	67%	0%	33%	67%	0%
12	PART LOCATING CAPABILITIES	75%	25%	0%	50%	25%	0%	50%	25%
13	VERTICAL SPEED (hoisting)	100%	0%	50%	50%	0%	75%	25%	0%
14	HORIZONTAL SPEED (cruising)	100%	0%	50%	50%	0%	75%	25%	0%
15	ACCELERATION	100%	0%	25%	75%	0%	25%	75%	0%
16	DECELERATION	100%	0%	25%	75%	0%	25%	75%	0%
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	100%	0%	0%	50%	25%	0%	75%	0%
18	VARYING INPUT/OUTPUT LOCATIONS	100%	0%	0%	50%	50%	0%	50%	50%
19	INPUT/OUTPUT PICK UP	100%	0%	0%	100%	0%	33%	33%	0%
20	STORAGE PICK UP	100%	0%	0%	100%	0%	33%	33%	0%
21	INPUT/OUTPUT DEPOSIT	100%	0%	0%	100%	0%	33%	33%	0%
22	STORAGE DEPOSIT	100%	0%	0%	100%	0%	33%	33%	0%
23	DWELL POINT STRATEGIES	67%	33%	0%	67%	0%	33%	33%	0%
24	SINGLE COMMAND RETRIEVAL SEQUENCING	67%	33%	0%	67%	0%	0%	67%	0%
25	DUAL COMMAND RETRIEVAL SEQUENCING	67%	33%	0%	67%	0%	0%	67%	0%
26	CORRECTIVE MAINTENANCE	100%	0%	0%	100%	0%	33%	33%	0%
27	PREVENTIVE MAINTENANCE	100%	0%	0%	100%	0%	33%	33%	0%
28	DUAL SHUTTLES	67%	33%	0%	67%	0%	0%	67%	0%
29	MULTIPLE S/R MACHINES	100%	0%	0%	100%	0%	0%	100%	0%
30	TIER ASSIGNED S/R MACHINES	100%	0%	0%	100%	0%	50%	50%	0%
31	AISLE TRANSFER CAR	100%	0%	0%	100%	0%	50%	50%	0%
32	ZONING	100%	0%	0%	50%	50%	50%	0%	50%

SECTION C: BELT/ROLLER CONVEYORS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	CONVEYOR GEOMETRY	100%	0%	100%	0%	0%	50%	0%	0%
2	DIRECTION OF TRAVEL	100%	0%	75%	25%	0%	50%	0%	0%
3	CONVEYOR SECTIONS	100%	0%	100%	0%	0%	25%	25%	0%
4	SPEED OF SECTIONS	75%	25%	75%	0%	0%	50%	0%	0%
5	LOAD SIZE	100%	0%	75%	0%	0%	50%	0%	0%
6	SPACING OF LOADS	75%	25%	75%	0%	0%	50%	0%	0%
7	SORTATION CAPABILITIES	75%	25%	25%	50%	0%	50%	25%	0%
8	ONBOARD OPERATIONS	75%	25%	0%	75%	0%	25%	50%	0%
9	TRANSFER FROM SECTIONS	100%	0%	33%	67%	0%	33%	33%	0%
10	TRANSFER OFF CONVEYOR	100%	0%	25%	75%	0%	50%	0%	0%
11	RIGHT ANGLE TRANSFER	100%	0%	0%	100%	0%	25%	50%	0%
12	LOADING TIME	100%	0%	25%	75%	0%	50%	0%	0%
13	UNLOADING TIME	100%	0%	25%	75%	0%	50%	0%	0%
14	CONVEYOR CAPACITY	100%	0%	100%	0%	0%	25%	25%	0%
15	BI-DIRECTIONAL TRANSFER	50%	50%	25%	25%	0%	0%	0%	25%
16	TWO WAY BELT CONVEYOR	100%	0%	50%	25%	0%	25%	25%	0%
17	LOADING/UNLOADING POINTS	100%	0%	75%	0%	0%	50%	0%	0%
18	MULTIPLE ENTRY/EXIT POINTS	75%	25%	75%	0%	0%	50%	0%	0%
19	SIMULTANEOUS ENTRIES/EXITS	75%	25%	50%	25%	0%	50%	25%	0%
20	ACCUMULATION	100%	0%	100%	0%	0%	67%	0%	0%
21	TRANSPORT	100%	0%	75%	0%	0%	50%	0%	0%
22	LOADS WITH UNEQUAL LENGTHS	75%	25%	75%	0%	0%	50%	0%	0%
23	SENSORS	75%	25%	0%	75%	0%	25%	50%	0%
24	PREVENTIVE MAINTENANCE	75%	25%	0%	75%	0%	50%	25%	0%
25	CORRECTIVE MAINTENANCE	75%	25%	0%	75%	0%	50%	25%	0%

SECTION D: GANTRY CRANES		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	BRIDGE SPEED	100%	0%	67%	33%	0%	100%	0%	0%
2	HOIST SPEED	100%	0%	33%	67%	0%	100%	0%	0%
3	PICKING DEVICE	100%	0%	33%	67%	0%	100%	0%	0%
4	ACCELERATION (bridge & hoist)	100%	0%	0%	100%	0%	33%	67%	0%
5	DECELERATION (bridge & hoist)	100%	0%	0%	100%	0%	33%	67%	0%
6	PICK UP TIME	100%	0%	33%	67%	0%	100%	0%	0%
7	DEPOSIT TIME	100%	0%	33%	67%	0%	100%	0%	0%
8	POSITIONING	100%	0%	33%	67%	0%	67%	33%	0%
9	JOB SEARCH PRIORITY	100%	0%	33%	67%	0%	100%	0%	0%
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	100%	0%	0%	100%	0%	0%	100%	0%
11	MULTIPLE CRANES ON RUNWAY	100%	0%	0%	100%	0%	0%	100%	0%
12	MULTIPLE CRANES IN DIFFERENT BAYS	100%	0%	33%	67%	0%	67%	33%	0%
13	INTERFERENCE	100%	0%	0%	100%	0%	33%	33%	33%
14	IDLE CRANE MANAGEMENT RULES	100%	0%	0%	100%	0%	33%	67%	0%
15	CORRECTIVE MAINTENANCE	100%	0%	0%	100%	0%	33%	67%	0%
16	PREVENTIVE MAINTENANCE	100%	0%	0%	100%	0%	33%	67%	0%
17	TRANSPORT OF MULTIPLE LOADS	100%	0%	33%	67%	0%	33%	67%	0%

SECTION E: INDUSTRIAL FORK TRUCKS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	100%	0%	100%	0%	0%	100%	0%	0%
2	TRAVEL TIME	100%	0%	100%	0%	0%	100%	0%	0%
3	PICK UP TIME	100%	0%	50%	50%	0%	100%	0%	0%
4	DEPOSIT TIME	100%	0%	50%	50%	0%	100%	0%	0%
5	HOME POSITION	100%	0%	25%	75%	0%	50%	50%	0%
6	ACCELERATION	75%	25%	50%	25%	0%	50%	25%	0%
7	DECELERATION	75%	25%	50%	25%	0%	50%	25%	0%
8	LIFT SPECIFICATIONS	75%	25%	0%	75%	0%	0%	75%	0%
9	JOB SEARCH PRIORITY	75%	25%	50%	25%	0%	75%	0%	0%
10	BATTERY RECHARGING	100%	0%	0%	100%	0%	50%	50%	0%
11	DISTANCE/TIME TRAVELED	100%	0%	100%	0%	0%	100%	0%	0%
12	VARYING SPEEDS	75%	25%	75%	0%	0%	75%	0%	0%
13	COLLISION AVOIDANCE	50%	50%	0%	50%	0%	0%	50%	0%
14	PATH	75%	25%	50%	25%	0%	50%	25%	0%
15	PASSING	50%	50%	0%	50%	0%	0%	50%	0%
16	ROUTING FROM PRESENT LOCATION	100%	0%	75%	0%	0%	75%	0%	0%
17	VEHICLE SELECTION	100%	0%	100%	0%	0%	100%	0%	0%
18	CORRECTIVE MAINTENANCE	100%	0%	0%	100%	0%	33%	67%	0%
19	PREVENTIVE MAINTENANCE	100%	0%	0%	100%	0%	33%	67%	0%
20	LOAD AND FIXTURE SEPARATION	75%	25%	0%	75%	0%	25%	50%	0%

SECTION F: INDUSTRIAL ROBOTS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	HOME POSITION	50%	50%	25%	25%	0%	0%	25%	0%
2	MULTIPLE DEGREES OF FREEDOM	50%	50%	0%	50%	0%	0%	0%	50%
3	VERTICAL TRAVERSE	50%	50%	0%	50%	0%	0%	25%	25%
4	RADIAL TRAVERSE	50%	50%	0%	50%	0%	0%	25%	25%
5	ROTATIONAL TRAVERSE	50%	50%	0%	50%	0%	0%	25%	25%
6	TRAVEL TIME	100%	0%	25%	75%	0%	50%	0%	25%
7	SPEED	100%	0%	50%	50%	0%	75%	0%	25%
8	SPEED FOR ALL DEGREES OF FREEDOM	50%	50%	0%	50%	0%	0%	0%	50%
9	PATH LOGIC	50%	50%	0%	50%	0%	0%	25%	25%
10	MULTIPLE TASKS PERFORMED	75%	25%	25%	50%	0%	50%	25%	0%
11	JOB SEARCH PRIORITIES	100%	0%	25%	75%	0%	100%	0%	0%
12	SEQUENCE VARIATION	100%	0%	33%	67%	0%	100%	0%	0%
13	PICK AND PLACE	100%	0%	0%	100%	0%	100%	0%	0%
14	MULTIPLE GRASPING ATTEMPTS	75%	25%	0%	75%	0%	0%	75%	0%
15	SENSORS	75%	25%	0%	75%	0%	25%	50%	0%
16	SHARED WORK ENVELOPE	50%	50%	0%	50%	0%	0%	25%	25%
17	MULTIPLE SERVICE STATIONS	67%	33%	0%	67%	0%	33%	33%	0%
18	CORRECTIVE MAINTENANCE	100%	0%	0%	100%	0%	33%	67%	0%
19	PREVENTIVE MAINTENANCE	100%	0%	0%	100%	0%	33%	67%	0%

SECTION A: AUTOMATED GUIDED VEHICLE SYSTEMS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	100%	0%	100%	0%	0%	100%	0%	0%
2	TRAVEL TIME	100%	0%	67%	33%	0%	100%	0%	0%
3	PICKUP TIME	100%	0%	33%	67%	0%	100%	0%	0%
4	DEPOSIT TIME	100%	0%	67%	33%	0%	100%	0%	0%
5	HOME POSITION	100%	0%	100%	0%	0%	100%	0%	0%
6	ACCELERATION	100%	0%	67%	33%	0%	67%	33%	0%
7	DECELERATION	100%	0%	67%	33%	0%	67%	33%	0%
8	EMPTY VEHICLE TRAVEL SPEED	100%	0%	100%	0%	0%	100%	0%	0%
9	REDIRECTION OF IN-TRANSIT VEHICLES	67%	33%	33%	0%	33%	33%	33%	0%
10	JOB SEARCH PRIORITIES	100%	0%	100%	0%	0%	100%	0%	0%
11	MAPPING (excluding shortest route)	100%	0%	33%	0%	67%	33%	67%	0%
12	SHORTEST ROUTE MAPPING	100%	0%	100%	0%	0%	67%	0%	0%
13	BATTERY RECHARGING	67%	33%	0%	33%	33%	0%	67%	0%
14	GUIDEPATH LAYOUT	100%	0%	100%	0%	0%	100%	0%	0%
15	SPURS	100%	0%	100%	0%	0%	100%	0%	0%
16	COLLISION AVOIDANCE	100%	0%	100%	0%	0%	100%	0%	0%
17	ZONE CONTROL	100%	0%	33%	33%	33%	33%	33%	33%
18	CONTROL SYSTEM	100%	0%	33%	0%	67%	33%	67%	0%
19	VEHICLE FLEET	100%	0%	100%	0%	0%	100%	0%	0%
20	HOMOGENOUS CHARACTERISTICS OF FLEET	100%	0%	100%	0%	0%	100%	0%	0%
21	MULTIPLE FLEETS	100%	0%	100%	0%	0%	100%	0%	0%
22	VEHICLE LIMITATIONS ON GUIDEPATH	100%	0%	100%	0%	0%	100%	0%	0%
23	ONBOARD OPERATIONS	100%	0%	33%	67%	0%	67%	33%	0%
24	PRESENT LOCATION VEHICLE ROUTING	100%	0%	67%	0%	33%	33%	67%	0%
25	CORRECTIVE MAINTENANCE	100%	0%	33%	33%	33%	67%	33%	0%
26	PREVENTIVE MAINTENANCE	100%	0%	33%	67%	0%	67%	33%	0%
27	BI-DIRECTIONAL TRAVEL	100%	0%	100%	0%	0%	100%	0%	0%
28	PASSING	100%	0%	33%	0%	67%	0%	100%	0%
29	REROUTING	100%	0%	33%	0%	67%	0%	100%	0%
30	PATH SEGMENT DOWNTIME	67%	33%	0%	0%	67%	0%	67%	0%
31	VEHICLE DISPATCHING RULES	100%	0%	100%	0%	0%	100%	0%	0%
32	VEHICLE SELECTION	100%	0%	100%	0%	0%	100%	0%	0%
33	EMPTY VEHICLE MANAGEMENT	100%	0%	100%	0%	0%	100%	0%	0%
34	MULTIPLE LOADS	67%	33%	0%	33%	33%	33%	0%	33%
35	VARYING PART TYPES	100%	0%	67%	0%	33%	67%	0%	33%
36	PRIORITIES AT INTERFACE POINTS	100%	0%	67%	0%	33%	67%	33%	0%
37	PARAMETER STATUS	100%	0%	0%	67%	33%	0%	33%	33%

	SECTION B: AUTOMATED STORAGE/RETRIEVAL SYSTEMS	Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	STORAGE RACK CONFIGURATION	100%	0%	100%	0%	0%	100%	0%	0%
2	INDIVIDUAL STORAGE (BIN) LOCATIONS	100%	0%	100%	0%	0%	100%	0%	0%
3	INDIVIDUAL STORAGE DIMENSIONS	100%	0%	50%	0%	50%	50%	50%	0%
4	VARYING STORAGE DIMENSIONS	100%	0%	50%	0%	50%	50%	50%	0%
5	MULTIPLE LOADS	100%	0%	50%	0%	50%	50%	50%	0%
6	CAPACITY SPECIFICATION	100%	0%	100%	0%	0%	100%	0%	0%
7	SHUFFLE CYCLES FOR DOUBLE DEEP BINS	100%	0%	0%	100%	0%	0%	100%	0%
8	STORAGE POLICIES	100%	0%	50%	0%	50%	50%	50%	0%
9	STORAGE LEVEL DETERMINATION	100%	0%	0%	50%	50%	0%	100%	0%
10	STORAGE RACKS ON BOTH SIDES	100%	0%	50%	0%	50%	50%	50%	0%
11	RETRIEVAL POLICIES	100%	0%	0%	50%	50%	0%	50%	0%
12	PART LOCATING CAPABILITIES	100%	0%	50%	0%	50%	50%	50%	0%
13	VERTICAL SPEED (hoisting)	100%	0%	100%	0%	0%	100%	0%	0%
14	HORIZONTAL SPEED (cruising)	100%	0%	100%	0%	0%	100%	0%	0%
15	ACCELERATION	100%	0%	100%	0%	0%	100%	0%	0%
16	DECELERATION	100%	0%	100%	0%	0%	100%	0%	0%
17	SIMULTANEOUS HORIZ. & VERT. TRAVEL	100%	0%	100%	0%	0%	100%	0%	0%
18	VARYING INPUT/OUTPUT LOCATIONS	100%	0%	100%	0%	0%	100%	0%	0%
19	INPUT/OUTPUT PICK UP	100%	0%	0%	100%	0%	100%	0%	0%
20	STORAGE PICK UP	100%	0%	0%	100%	0%	100%	0%	0%
21	INPUT/OUTPUT DEPOSIT	100%	0%	0%	100%	0%	100%	0%	0%
22	STORAGE DEPOSIT	100%	0%	0%	100%	0%	100%	0%	0%
23	DWELL POINT STRATEGIES	50%	50%	0%	50%	0%	50%	0%	0%
24	SINGLE COMMAND RETRIEVAL SEQUENCING	100%	0%	50%	50%	0%	50%	50%	0%
25	DUAL COMMAND RETRIEVAL SEQUENCING	100%	0%	50%	50%	0%	50%	50%	0%
26	CORRECTIVE MAINTENANCE	50%	50%	0%	50%	0%	50%	0%	0%
27	PREVENTIVE MAINTENANCE	100%	0%	0%	50%	50%	50%	50%	0%
28	DUAL SHUTTLES	0%	100%	0%	0%	0%	0%	0%	0%
29	MULTIPLE S/R MACHINES	100%	0%	100%	0%	0%	100%	0%	0%
30	TIER ASSIGNED S/R MACHINES	100%	0%	100%	0%	0%	100%	0%	0%
31	AISLE TRANSFER CAR	50%	50%	0%	50%	0%	0%	50%	0%
32	ZONING	100%	0%	100%	0%	0%	100%	0%	0%

SECTION C: BELT/ROLLER CONVEYORS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	CONVEYOR GEOMETRY	100%	0%	33%	67%	0%	100%	0%	0%
2	DIRECTION OF TRAVEL	100%	0%	33%	67%	0%	100%	0%	0%
3	CONVEYOR SECTIONS	100%	0%	33%	67%	0%	100%	0%	0%
4	SPEED OF SECTIONS	100%	0%	33%	67%	0%	100%	0%	0%
5	LOAD SIZE	67%	33%	33%	33%	0%	67%	0%	0%
6	SPACING OF LOADS	67%	33%	33%	33%	0%	67%	0%	0%
7	SORTATION CAPABILITIES	67%	33%	33%	33%	0%	67%	0%	0%
8	ONBOARD OPERATIONS	100%	0%	33%	33%	0%	33%	33%	0%
9	TRANSFER FROM SECTIONS	100%	0%	33%	67%	0%	100%	0%	0%
10	TRANSFER OFF CONVEYOR	100%	0%	33%	67%	0%	100%	0%	0%
11	RIGHT ANGLE TRANSFER	100%	0%	33%	67%	0%	67%	33%	0%
12	LOADING TIME	100%	0%	33%	67%	0%	100%	0%	0%
13	UNLOADING TIME	100%	0%	33%	67%	0%	100%	0%	0%
14	CONVEYOR CAPACITY	100%	0%	33%	67%	0%	100%	0%	0%
15	BI-DIRECTIONAL TRANSFER	100%	0%	0%	100%	0%	33%	67%	0%
16	TWO WAY BELT CONVEYOR	100%	0%	0%	100%	0%	0%	100%	0%
17	LOADING/UNLOADING POINTS	100%	0%	33%	67%	0%	100%	0%	0%
18	MULTIPLE ENTRY/EXIT POINTS	100%	0%	33%	67%	0%	100%	0%	0%
19	SIMULTANEOUS ENTRIES/EXITS	100%	0%	33%	67%	0%	100%	0%	0%
20	ACCUMULATION	100%	0%	33%	67%	0%	100%	0%	0%
21	TRANSPORT	100%	0%	33%	67%	0%	33%	67%	0%
22	LOADS WITH UNEQUAL LENGTHS	67%	33%	0%	67%	0%	33%	33%	0%
23	SENSORS	100%	0%	33%	67%	0%	67%	33%	0%
24	PREVENTIVE MAINTENANCE	100%	0%	33%	67%	0%	67%	33%	0%
25	CORRECTIVE MAINTENANCE	100%	0%	33%	67%	0%	67%	33%	0%

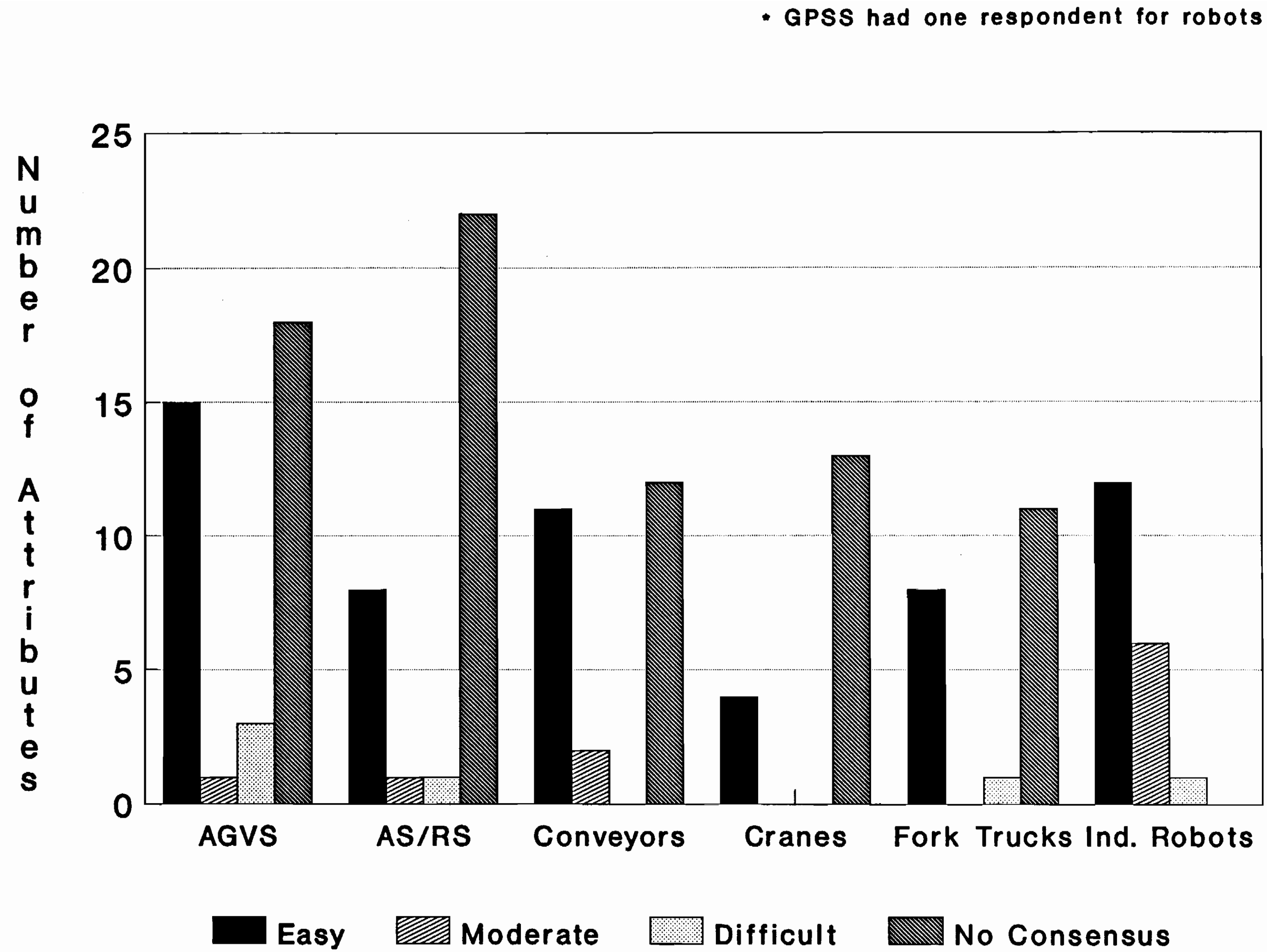
SECTION D: GANTRY CRANES		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	BRIDGE SPEED	100%	0%	67%	33%	0%	100%	0%	0%
2	HOIST SPEED	67%	33%	67%	0%	0%	67%	0%	0%
3	PICKING DEVICE	67%	33%	0%	67%	0%	67%	0%	0%
4	ACCELERATION (bridge & hoist)	67%	33%	67%	0%	0%	67%	0%	0%
5	DECELERATION (bridge & hoist)	67%	33%	67%	0%	0%	67%	0%	0%
6	PICK UP TIME	100%	0%	0%	100%	0%	100%	0%	0%
7	DEPOSIT TIME	100%	0%	0%	100%	0%	100%	0%	0%
8	POSITIONING	100%	0%	67%	33%	0%	100%	0%	0%
9	JOB SEARCH PRIORITY	100%	0%	100%	0%	0%	100%	0%	0%
10	SIMULTANEOUS HOIST & BRIDGE TRAVEL	67%	33%	67%	0%	0%	67%	0%	0%
11	MULTIPLE CRANES ON RUNWAY	100%	0%	100%	0%	0%	100%	0%	0%
12	MULTIPLE CRANES IN DIFFERENT BAYS	100%	0%	100%	0%	0%	67%	33%	0%
13	INTERFERENCE	100%	0%	100%	0%	0%	100%	0%	0%
14	IDLE CRANE MANAGEMENT RULES	67%	33%	33%	0%	33%	33%	33%	0%
15	CORRECTIVE MAINTENANCE	67%	33%	33%	33%	0%	33%	33%	0%
16	PREVENTIVE MAINTENANCE	100%	0%	33%	67%	0%	67%	33%	0%
17	TRANSPORT OF MULTIPLE LOADS	33%	67%	33%	0%	0%	0%	0%	33%

SLAM

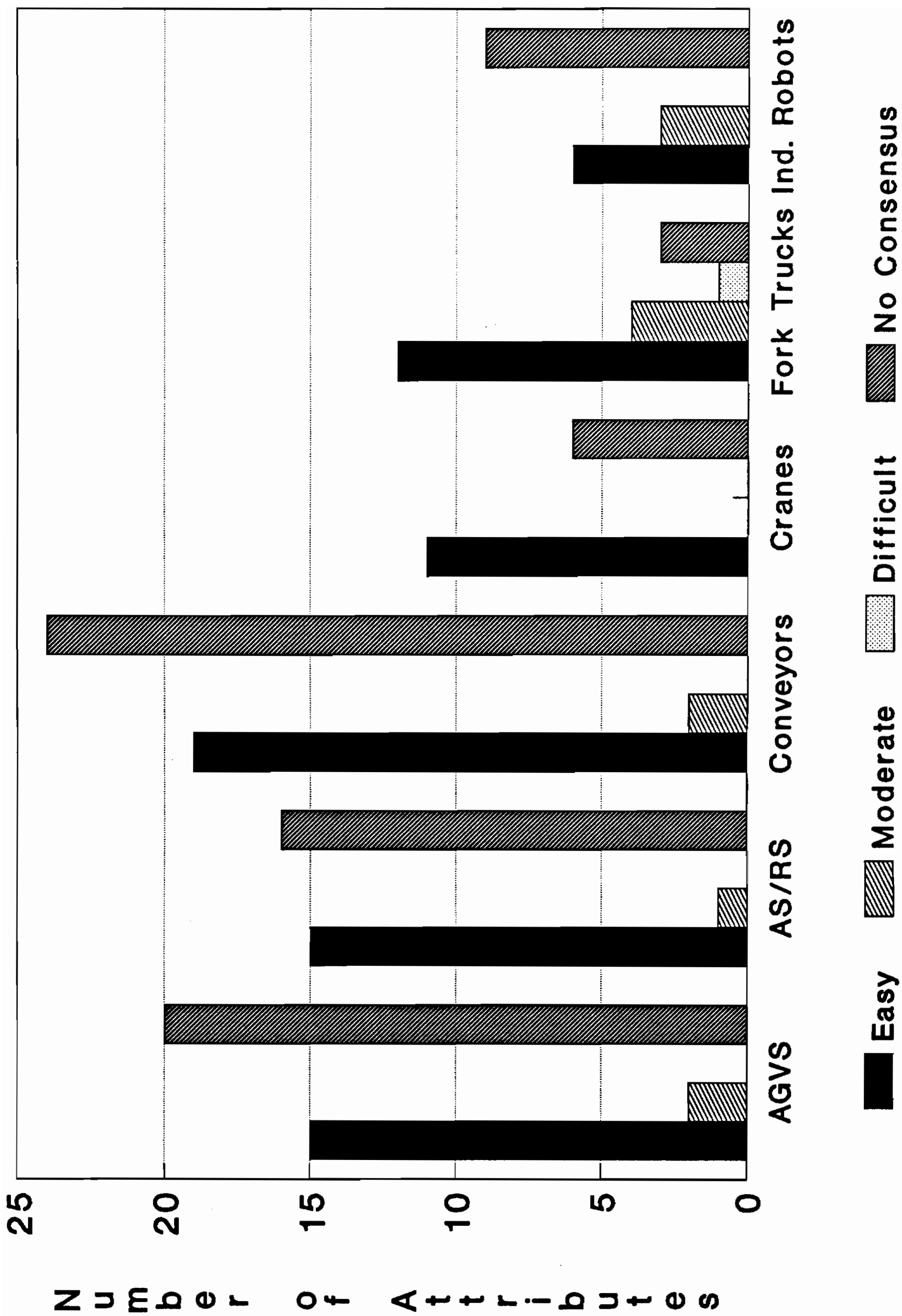
SECTION E: INDUSTRIAL FORK TRUCKS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	SPEED	100%	0%	33%	67%	0%	100%	0%	0%
2	TRAVEL TIME	100%	0%	33%	67%	0%	100%	0%	0%
3	PICK UP TIME	100%	0%	33%	67%	0%	100%	0%	0%
4	DEPOSIT TIME	100%	0%	33%	67%	0%	100%	0%	0%
5	HOME POSITION	67%	33%	33%	33%	33%	67%	33%	0%
6	ACCELERATION	0%	100%	0%	0%	0%	0%	0%	0%
7	DECELERATION	0%	100%	0%	0%	0%	0%	0%	0%
8	LIFT SPECIFICATIONS	50%	50%	0%	25%	0%	0%	25%	0%
9	JOB SEARCH PRIORITY	100%	0%	33%	67%	0%	67%	33%	0%
10	BATTERY RECHARGING	67%	33%	0%	67%	0%	0%	67%	0%
11	DISTANCE/TIME TRAVELED	100%	0%	33%	33%	33%	67%	33%	0%
12	VARYING SPEEDS	100%	0%	33%	33%	0%	67%	33%	0%
13	COLLISION AVOIDANCE	67%	33%	33%	0%	33%	33%	0%	33%
14	PATH	100%	0%	33%	33%	33%	33%	67%	0%
15	PASSING	100%	0%	33%	33%	33%	33%	67%	0%
16	ROUTING FROM PRESENT LOCATION	100%	0%	33%	33%	33%	33%	67%	0%
17	VEHICLE SELECTION	100%	0%	33%	67%	0%	67%	33%	0%
18	CORRECTIVE MAINTENANCE	100%	0%	33%	67%	0%	67%	33%	0%
19	PREVENTIVE MAINTENANCE	100%	0%	33%	67%	0%	67%	33%	0%
20	LOAD AND FIXTURE SEPARATION	100%	0%	33%	67%	0%	33%	67%	0%

SECTION F: INDUSTRIAL ROBOTS		Modeling Capability		Modeling Method			Level of Difficulty		
		Yes	No	DIRECT	INDIRECT	EXTERNAL	EASY	MODERATE	DIFFICULT
1	HOME POSITION	67%	33%	0%	67%	0%	33%	33%	0%
2	MULTIPLE DEGREES OF FREEDOM	67%	33%	0%	33%	33%	0%	33%	33%
3	VERTICAL TRAVERSE	67%	33%	0%	33%	33%	0%	33%	33%
4	RADIAL TRAVERSE	67%	33%	0%	33%	33%	0%	33%	33%
5	ROTATIONAL TRAVERSE	67%	33%	0%	33%	33%	0%	33%	33%
6	TRAVEL TIME	67%	33%	0%	67%	0%	33%	33%	0%
7	SPEED	67%	33%	0%	67%	0%	33%	33%	0%
8	SPEED FOR ALL DEGREES OF FREEDOM	67%	33%	0%	33%	33%	0%	67%	0%
9	PATH LOGIC	33%	67%	0%	33%	0%	0%	33%	0%
10	MULTIPLE TASKS PERFORMED	67%	33%	0%	33%	33%	33%	33%	0%
11	JOB SEARCH PRIORITIES	67%	33%	33%	33%	0%	33%	33%	0%
12	SEQUENCE VARIATION	67%	33%	0%	67%	0%	0%	67%	0%
13	PICK AND PLACE	67%	33%	0%	33%	33%	33%	33%	0%
14	MULTIPLE GRASPING ATTEMPTS	67%	33%	0%	33%	33%	0%	67%	0%
15	SENSORS	67%	33%	0%	67%	0%	33%	33%	0%
16	SHARED WORK ENVELOPE	67%	33%	0%	67%	0%	33%	33%	0%
17	MULTIPLE SERVICE STATIONS	67%	33%	0%	67%	0%	33%	33%	0%
18	CORRECTIVE MAINTENANCE	100%	0%	33%	67%	0%	67%	33%	0%
19	PREVENTIVE MAINTENANCE	100%	0%	33%	67%	0%	67%	33%	0%

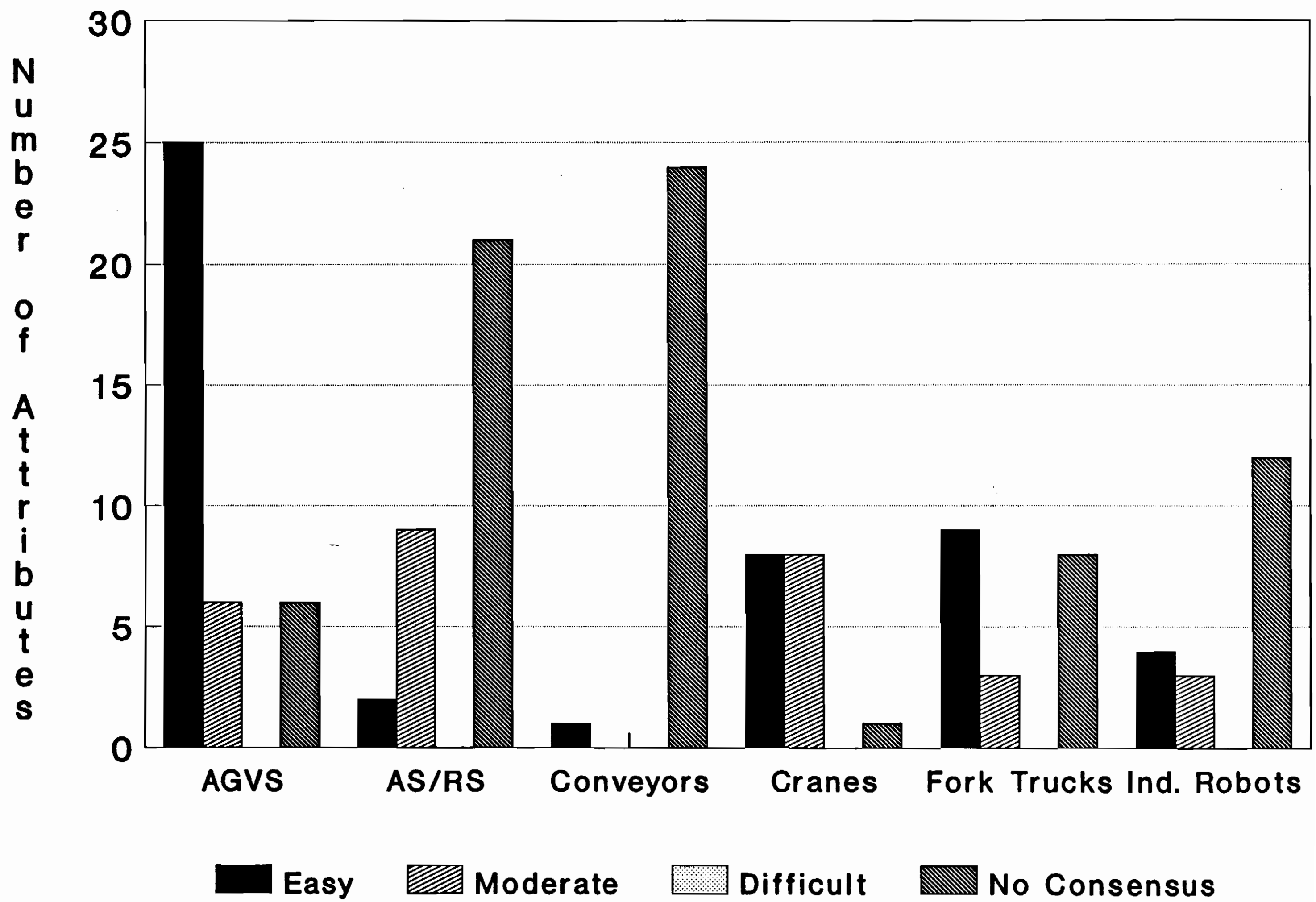
APPENDIX D: HISTOGRAMS OF LEVELS OF DIFFICULTY



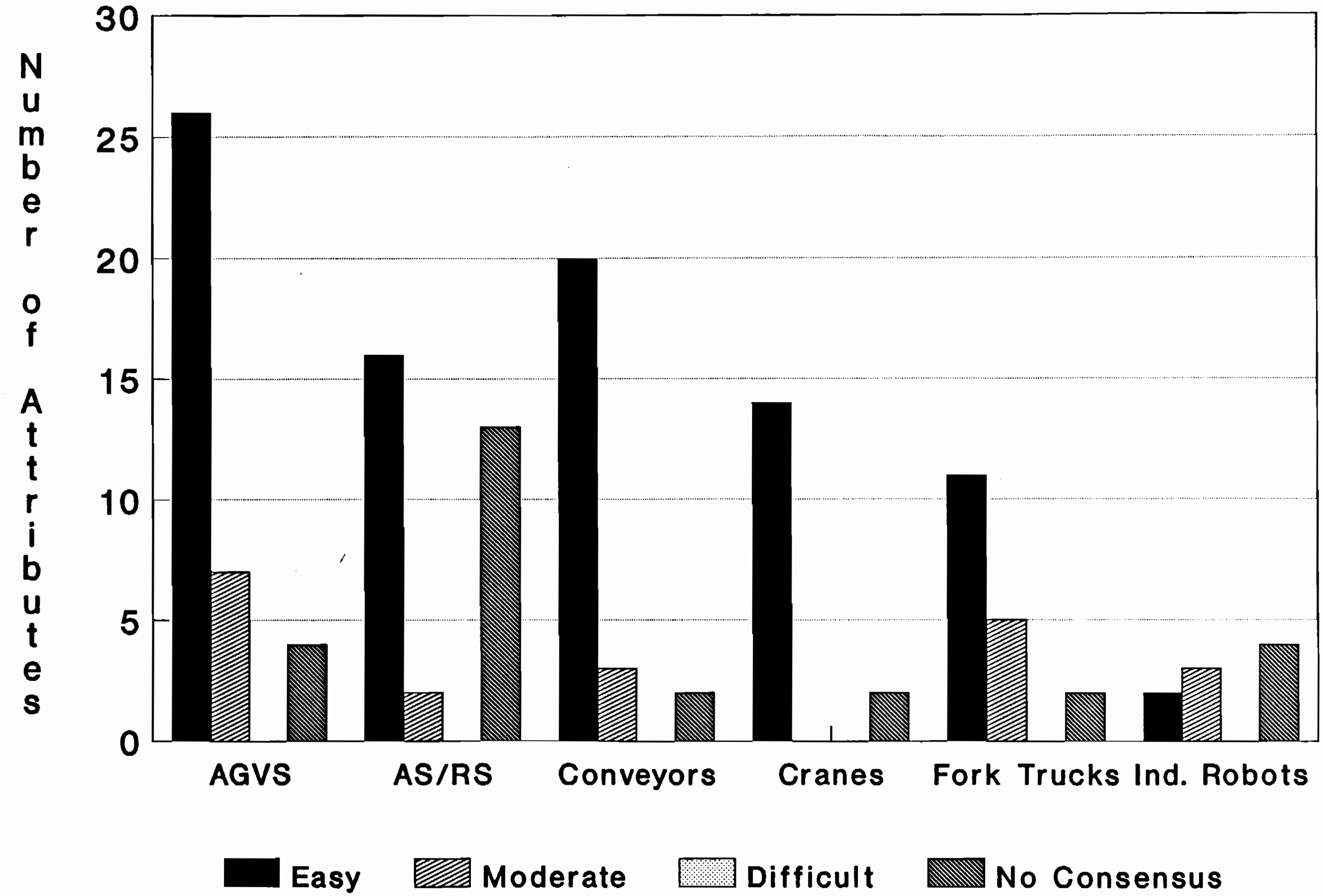
Levels of Difficulty for GPSS



Levels of Difficulty for PROMODEL



Levels of Difficulty for SIMAN



Levels of Difficulty for SLAM

VITA

Pamela Renita Comer, daughter of William and Rosa Comer, was born on November 19, 1968, in Oxford, North Carolina. She is the youngest of six children.

In May of 1991, Ms. Comer received her Bachelor of Science degree in Industrial Engineering from North Carolina Agricultural and Technical State University in Greensboro, NC. She graduated summa cum laude and was the president of the University's chapter of the Institute of Industrial Engineering. She was affiliated with various other professional organizations and received other honors while pursuing her B.S. and M.S. degrees. She received her Master of Science degree from Virginia Polytechnic Institute and State University in the Summer of 1993.

Ms. Comer has currently accepted a position with IBM in Research Triangle Park, North Carolina. There she will be working as an Associate Engineer within one of their manufacturing facilities.

Pamela Renita Comer