NISTIR 5614

Japan Technology Program Assessment

Simulation: State-of-the-Art in Japan

Albert Jones
Editor

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology
Manufacturing Engineering Lab
Gaithersburg, MD 20899

NIST

OFFICE OF TECHNOLOGY POLICY
OTP

NISTIR 5614

Japan Technology Program Assessment

Simulation: State-of-the-Art in Japan

Albert Jones
Editor

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards
and Technology
Manufacturing Engineering Lab
Gaithersburg, MD 20899

March 1995

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

TECHNOLOGY ADMINISTRATION
Mary L. Good, Under Secretary for Technology

NATIONAL INSTITUTE OF STANDARDS
AND TECHNOLOGY
Arati Prabhakar, Director

SIMULATION IN JAPAN: A STATE-OF-THE ART REPORT

Prepared for:

Department of Commerce
Office of Technology Policy
Japan Technology Program

Edited by:

Albert Jones
National Institute of Standards and Technology

Contributing Authors:

Susumu Morito, Waseda University
Shigeki Umeda, Musahi University
Jerry Banks, Georgia University of Technology
Wayne Davis, University of Illinois
Hank Grant, University of Oklahoma
Leslie Interrante, University of Alabama at Hunstville
Yuehwern Yih, Purdue University

Abstract

This report summarizes the current state-of-the-art of simulation in Japan, and provides some insight into the future directions the Japanese are likely to pursue. It is divided into three parts. In part one, we provide a translation of a paper that was published in Journal of the Operations Research Society of Japan by Shigeki Umeda and Susumu Morito. In part two, we provide a copy of a paper by Shigeki Umeda which is contained in the proceedings of the recently held conference on New Directions in Simulation for Manufacturing and Communications. These authors have graciously agreed to allow their papers to be included in this report. In part three, we provide comments from five US researchers who attended the conference on New Directions in Simulation for Manufacturing and Communications.

In an effort to strengthen U.S. competitiveness, see that U.S. industry becomes more aware of developments in Japan, and fulfill the mandate of the Japanese Technical Literature Act, the Department of Commerce's Office of Technology Policy Japan Technology Program has commissioned this report. The Japanese Technical Literature Act requires the Secretary of Commerce to prepare annual reports regarding important Japanese scientific discoveries and technical innovations.

Executive Summary

Simulation is a computer-based tool which can be used to characterize and to analyze the physical, logical, and operational aspects of manufacturing products, processes, and systems. Today, simulation provides, in many cases, the only viable technique for carrying out these analyses. Consequently, the resulting simulation models have the potential to provide input to every decision that gets made about these products, processes, and systems.

This report summarizes the current state-of-the-art of simulation in Japan, and provides some insight into the future directions the Japanese are likely to pursue. It is divided into three parts. In part one, we provide a translation of a paper that was published in Journal of the Operations Research Society of Japan by Shigeki Umeda and Susumu Morito. In part two, we provide a copy of a paper by Shigeki Umeda which is contained in the proceedings of the recently held conference on New Directions in Simulation for Manufacturing and Communications. These authors have graciously agreed to allow their papers to be included in this report. In part three, we provide comments from five US researchers who attended the conference on New Directions in Simulation for Manufacturing and Communications.

Several general conclusions are drawn regarding the current state-of -the-art in simulation in Japan. First, the large number of industry-authored papers and applications-oriented papers presented at the conference seems to suggest that simulation is much more prevalent in the industrial laboratories and systems engineering departments than in academic institutions. Most of the industry-authored papers described applications that are currently in use. This is true of many of the academic- and jointly-authored papers as well. The systems engineering department of the firm is typically the focus of application development, with assistance from industrial engineering and field workers. One advantage of this approach is to ease the integration of simulation modeling with other information technology such as existing databases and MIS applications. In addition, the rate of increase of simulation applications for industry in Japan seems to be growing rapidly. More simulation applications are developed in-house, and very few are contracted to outside firms. Japanese companies seem to have more tightly-coupled research and development, product development, and operations departments or divisions, which eases simulation application development considerably. The Japanese tend to measure the payoff of a particular application at the system level rather than the component level. Although this technique gives less information regarding the simulation alone, more information is provided regarding the contribution of the total software application when the simulation is an embedded component of a larger system.

Second, Japanese computer manufacturers (such as Hitashi, Toshiba, and NEC) play a large part in simulation application development. It appears that more applications of simulation to heavy industry, developed by the particular industry, exist in Japan. The volume of simulation-related research in Japan, however, is considerably lower than that in the United States The industrial laboratories of these large companies perform basic research and advanced development in a number of areas including simulation. For example, Toshiba has five research laboratories that conduct long-range (5-10 years) research in such areas as computer hardware, manufacturing, and software. Toshiba also has eight development laboratories for mid-term research (3-5 years). In 1991, Toshiba spent 8.2 percent of its annual net sales (approximately $22.9 billion) on research. Work in such laboratories seems to be tightly coupled with application or product development. Although many new ideas originate in the United States and Europe, the Japanese can rapidly develop the technology and transfer it into applications.

As for the future, there seems to be a large amount of work in combining simulation analysis with both OR and AI analyses, with the bulk of the combined-analysis papers describing simulation-AI integration. The telecommunications industry seems to be leading in this thrust. Object-oriented modeling also seems to be on the increase. Several small OOP-based modeling libraries are mentioned in the papers, and the development of such libraries is expected to increase. One is the main applications of these new tools will be to the development of distributed simulation applied to a Virtual Plant System (VPS), which includes both on-line factory simulation and real-time monitoring. Both plant information flow and material flow are considered. As part of the integrated system, the planning module sends plant control data to both the actual plant and the virtual (simulated) plant. Manufacturers will be able to use such a computing environment to predict the key events in a plant and to support rescheduling operations in real time.

The Japanese are moving toward open, client-server architectures, as in the United States. Several related ongoing research projects and future trends are likely to affect the future of computing in Japan. The Japanese are emerging as leader in fuzzy logic (e.g., the LIFE project funded by MITI, 1990) and massively parallel symbolic computing (e.g., the ICOT project funded over the last 13 years by MITI). Industry and government participation in large, long-term research projects of this type serve as the basis for much research in Japan. There tends to be a tighter coupling between research and applications in such projects than in the United States.

Because of their emphasis on using simulation as an on-line tool, the Japanese are devoting less effort to the statistical analysis of output data, because it is not applicable to their real-time concerns. Instead, they are pushing, as indicated above, toward virtual manufacturing including an increased capability in real-time simulation and scheduling. This research includes the development of an integrated framework for virtual manufacturing and the development of technologies for distributed simulation needed to support the real-time simulation requirements. Furthermore, they have recognized the need for integrating real-time process simulation with real-time shop floor simulation.

In summary, there are some similarities and many notable differences between the evolution of simulation in the United States and in Japan. In the area of commercialization, the United States is far ahead, and is likely to remain in that position. Almost none of the commercial tools used in Japanese universities and companies are developed and sold by Japanese vendors. However, there seems to be larger number of in-house tools used in Japan. In the United States, there is a significant amount of university training in simulation; the number of universities teaching simulation in Japan is quite small. On the other hand, there tends to be a tighter coupling of universities with industry in Japan than in the United States. As for research, most of the theoretical simulation research is done in universities in the United States; Japanese research focuses mostly on applications. Most of the new research in Japan both in the university and industrial research labs is on new applications of simulation including distributed simulation, hybrid tools, real-time simulation, and virtual manufacturing. While it is true that these same application areas are being investigated in the United States, the Japanese are, if anything, even or slightly ahead in these areas.

Introduction

This report summarizes the state of the art of simulation research and development in Japan. This summary is divided into three parts. In part one, we provide a translation of a paper that was published in Journal of the Operations Research Society of Japan by Shigeki Umeda and Susumu Morito. In part two, we provide a copy of a paper by Shigeki Umeda which is contained in the proceedings of the recently held conference on New Directions in Simulation for Manufacturing and Communications. These authors have graciously agreed to allow their papers to be included in this report. In part three, we provide comments from five US researchers who attended the conference on New Directions in Simulation for Manufacturing and Communications.

PART 1

Current Status and Future Prospects of Discrete Event System Simulation

Shigeki Umeda and Susumu Morito

1. Introduction

Demand for discrete system simulation has been increasing lately as reflected in the successive development of many software for it . On the other hand, the downsizing of computers has made it possible to purchase high performance computers at a moderate price. This trend has resulted in the marked improvement in computer environments for simulation.

In this paper, we discuss the current usage status of simulation by referring to a recent survey, which is a follow-up to a previous survey conducted in 1987. Like the previous survey, this one was conducted by questionnaire. The goal was to determine

1) the current status of simulation users and simulation projects,
2) the current status of simulation software, and
3) the new needs for and trends in simulation.

2. Survey Subjects and Results

2.1 Subjects

The survey was conducted by mail during April and May of 1993. The 7 page survey requested the name of the responders, and consisted of a mixture of multiple-choice and descriptive-type questions. The initial list of potential recipients of the survey included approximately 180 companies who were members of the Japan Operation Research Society, and to approximately 140 companies who were suggested by the five vendors of discrete event software. Since there was a small overlap in these lists, the final number of survey subjects was 317 companies. Of those contacted, 128 companies responded (with multiple responses coming from several companies) resulting in a response rate of 40.4%. This report constitutes a summary of those responses.

In the 1987 survey there were many returns with no clear understanding of the differences between discrete event simulation and other types of simulation. In this case, only one return demonstrated this type of misunderstanding - it was eliminated from the final results. This indicates discrete event simulation is better understood any well accepted by industry.

2.2 Applications and Purpose of Simulation

As can be seen from Table 1, many simulation applications (155/277) are found in the factory systems such as manufacturing lines and related systems. The number of these systems, together with the computer and telecommunications systems are still increasing over the numbers reported in the 1987 survey. Significant increases, compared with the 1987 survey , were found in materials handling systems including AGVs, cranes, distribution systems, and automated warehouses.

Table 1. Applications of Simulation

	Pre-Assessment	Improvement plan data	Control of daily tasks	Others	Total
Manufacturing lines	60	36	11	3	110
Material Handling AGV/Crane	41	6			47
Material Transport Distribution Systems	30	13	1		44
Computer Systems	13	5	1	2	21
Automated Warehouse	15	5			20
Traffic Flow Parking lots	13	3	2	2	20
Telecommunication & networking systems	12	3			15
Others	4	3	1	2	10
Totals	178	74	16	9	277

Logistics-related systems such as the distribution/transport systems are among the newest application areas for simulation. There were 17 respondents that indicated that, although they are not doing so at present, they intended to develop simulation models for their material handling systems. There are two reasons for this. First, factory automation is becoming more advanced and manufacturing line simulation is more widely accepted. Second, there is an evolving notion that material handling systems are the primary interface between the manufacturing systems and the front office sales.

As in our earlier survey, the predominant applications of simulation are for pre-evaluation of system design, layout, and flow analysis and for the preparation of improvement data. But, this survey indicated an increasing use of simulation for the control of daily operations. Those respondents who are doing this are also using simulation for pre-evaluation and improvement activities. This increase of simulation on the shop floor, is a good measure of the growing confidence and acceptance of simulation in Japanese industry. As this confidence and acceptance increases, we expect the use of simulation as a means of controlling shop floor operations to increase.

Table 2. Years of Simulation Introduction

Years of Introduction	-74	75-79	80-84	85-90	90-
No. of Cases	16	8	7	28	27

As can be seen from Table 2, the rate at which simulation is being introduced in Japanese industries has increased dramatically in the last ten years.

2.3 Simulation Projects

The manpower needed for developing simulation projects varies from large scale efforts to small scale efforts. In this survey, we asked what size projects are handled in terms of the large-, medium-, and small- scale efforts (Figures 1-3).

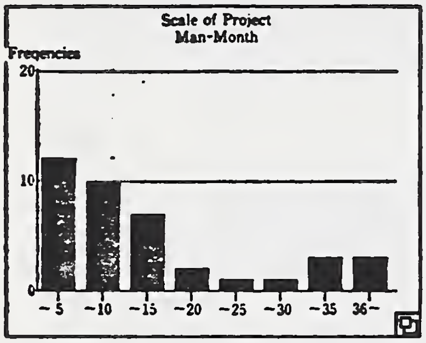

Figure 1. Large scale projects

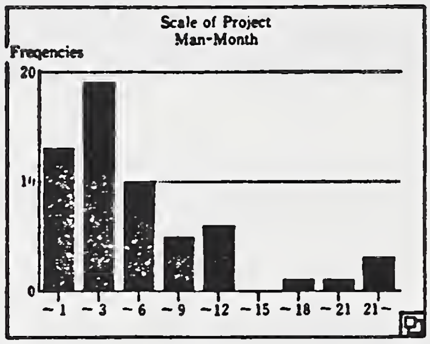

Figure 2. Medium scale projects

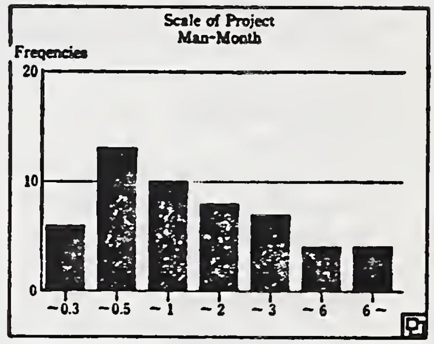

Figure 3. Small scale projects

What is considered to be a "large" project varied from 5 to 36 man-months. A "medium" project varied from 1 to 21 man-months, and a "small" project from .3 to 6 man-months. As we discovered in our 1987 survey, the predominant development effort was 2-3 man-months. There were, however, very few projects in our previous survey that required larger than a 6 month effort or that lasted longer than one year. This survey revealed a general increase in the number of large scale projects.

As indicated in Table 3, most of these projects are undertaken by either "systems", work sites, or I.E. departments within the company. Other projects are conducted by the manufacturing and material handling departments, This implies that simulation is widely used throughout many companies

Table 3. Development Teams and Users of Simulation Projects

	Development Teams	Users
I.E. Department	21	10
Systems Department	43	20
Work Sites	34	54
Others	15	7

2.4 Current Status on the Use of Simulation Software

Rather than use specific simulation languages such as GPSS, SLAM, and SIMAN, there are many cases in which software packages such as WITNESS and AutoMod or general purpose programming languages such as FORTRAN and C are actively used. In fact, as seen in Table 4, there are more companies using software packages and programming languages that using simulation languages.

The reasons for this trend are that

1) User skills have improved, and the computer down-sizing permits the use of many different tools.
2) Different simulation systems can be used to fit different applications, different degree of knowledge and preference of the developers, and the different animation needs of the users.

3) The subjects of simulation have become more complex and large-scale so that one type of simulation software cannot satisfy all needs.

Table 4. The Usage of Simulation Software

Software Usage	Number of Cases
Simulation language software only	21
Package Software only	16
General purpose language software only	1
Simulation language and general purpose languages	15
Simulation language and package software	14
Packages and general purpose languages	3
All three types	23

When users select simulation software, they tend to give top priority to the software's ability to describe their model (see Table 5). At the same time, the users are concerned with the easy-to-use and easy-to-learn features. Price is not a major consideration anymore. The easy-to-customize feature is more important than price. The trend is toward software which can satisfy the users' needs in building their own complex models and compatibility between their simulation programs with other application software.

Table 5. Selection Criteria (first and second choice)

Selection Criteria	Number of Cases
Model Description Capability	66
Easy-to-use/Easy-to-learn	57
Easy to Customize	23
Price	15
System Support	5
Number of users	3
Others	3

There is an increasing number of cases in which different simulation software packages are used for different purposes (34). This situation occurs where the simulation has been used for many years or when many different departments are very active in simulation. Different problems require different programs. For example, packaged software are used relatively frequently when the scale of the simulation project is small and the modeling capability provided by the package is sufficient.

The effects of computer down-sizing is clearly shown in Table 6.

Table 6. Computing Environment of Simulation Users

Type of Hardware	Number of Cases
Workstation	26
PC	19
PC and Workstation	21
Mainframe and Workstation	6
Mainframe and PC	6
Mainframe	5
All three types	10

Those using the mainframe constitute only 6% of the total. Conversely, more than 70 % of the responders do not use mainframe at all for their simulation projects. As far as reusability of simulation models is concerned, approximately 40% of the responders (51) do not reuse their models. The remaining 60% have reused models only two or three times. It appears that the expeditious implementation of new models is more widespread that the recycling of used models.

2.5 Statistical Models vs. Deterministic Models

Of those who responded to the survey, 30 use only statistical models (involving random numbers), 11 use only deterministic models, and 45 make use of both types.

2.6 Simultaneous Use of Simulation with Statistical Analysis and Experimental Design

Approximately ½ of the responders said that they used statistical analysis techniques to analyze the output from their simulation runs (see Table 7). This indicates that many users are beginning to understand the importance of statistics in analyzing simulation output. As for experimental design techniques, a significant majority said that they do not use them to design the simulation study. This is probably due to the fact that these simulation users are not familiar with experimental design techniques.

Table 7. Simultaneous Use of Simulation with Statistical Analysis and Experimental Design

	Statistical Analysis	Experimental Design
Use	38	25
Do not use	41	56

2.7 New Interface and Programming Environment Tools

Users expressed several desires related to the interface and programming environments for simulation. Table 8 tabulates these desires.

Table 8. New Interface and Programming Environment Tools

Need	1st rank	2nd rank	3rd rank
Support tools for Model Development	47	17	13
Statistical Output Analysis	25	28	20
Animation and Graphics	18	25	27

1) More support tools for model building including graphical model generators, mode editors, easy-to-learn modeling tools/environments, and improved debugging capabilities;

2) Improved visual functions such as animation, graphical display of results, and video projectors;

3) Improvement of input data conversion capability including direct data input from spread sheet programs, direct transfer of real-time data on equipment performance from the factory modeling systems to the simulator, standardization of input/output data, and preparation of parameter databases; and

4) High speed execution of simulation models.

2.9 Popular OR Methods Among Simulation Users

Table 9 summarizes the responses from the survey from the 93 companies who are active users of discrete event simulation regarding their use of other techniques from the fields of Operations Research and

Artificial Intelligence.

Table 9. Other OR Methods Employed by Simulation Users

Methods	Frequency	Methods	Frequency
Discrete Event Simulation	93	Reliability Theory	14
Artificial Intelligence	35	Network Programming	15
Linear Programming	34	Other simulations	13
Continuous Simulation	33	Dynamic Programming	10
Queuing Theory	33	Markov Models	10
Scheduling Theory	31	Search Theory	8
PERT/CPM	27	AHP	6
Inventory Models	21	Exchange Theory	1
Non-Linear Programming	17	Integer Programming	14

As seen from the table, about 1/3 of the companies who use discrete event simulation do not use any other OR methods. The remaining 2/3 use a wide range of methods. It is clear from this table that traditional OR methods such as linear Programming and PERT/CPA are still widely used in conjunction with simulation. However, we are some skeptical regarding the actual vs. reported use of methods such as Queuing and Scheduling Theory together with simulation.

Among the 35 companies which are not using discrete event simulation, 12 use Artificial Intelligence, 11 use Linear Programming, 5 use Scheduling Theory, and 4 use continuous simulation.

3. Simulation and Systems Integration

3.1 Simulation as an Integration Tool

With the development of the so-called systems integration business, simulation has been increasingly regarded as both a solution tool and an integration tool. There were many responses (53) to the question "Please state your views on the relationship between simulation and systems integration?" These responses can be divided into to classes: those who limit integration to off-line activities, and those who want to use integration on-line to link daily tasks.

By off-line activities we mean: tools for production planning for CIM, tools for design evaluation, tools for constructing evaluation and analysis system, tools for cost analysis, tools for inspection, and tools for system optimization. In these cases, simulation is viewed as a supporting tool to carry out these activities. Those using simulation in this role noted the importance of graphical displays and animation of simulation results as a simulation interface.

By on-line daily tasks we mean: fusion of simulation into existing production control system, evaluation tools for daily scheduling activities, support tool for daily planning activities, and fusion of simulation with shop floor monitoring systems. This use of simulation as an on-line tool is becoming more popular (58 positive responses) and more companies (47) are using these new capabilities to routinely change simulation parameters in real-time.

3.2 Connection of Simulation Input/Output Data with External Files

In order to perform on-line simulation, it is necessary for the simulation models to be connected to some external file or database system. Some successful examples sited in the survey are listed below.

1) The data down-loaded from factory computers becomes input data for simulation through LAN/data converters.

2) Simulation is done at workstation and its output is transferred to PCs via LAN for statistical analysis.

3) Simulation output is made compatible with the inputs to commercial tabular calculation programs such as LOTUS 1-2-3 with data conversion if necessary.

4) Data are collected from the production control databases and converted into files compatible with the tabular programs and statistical data analysis packages, which are then transferred to the simulations.

5) Simulation input parameters are produced directly from factory process control databases.

6) Network the workstation, on which the simulation programs are running, with personal computers such as PCs and Macintosh.

4. Summary

Items to be improved for future simulation activities are: increase run-time speed, improve interface tools for model building and results display, and integration with other manufacturing applications and databases. If these are accomplished, we expect the number and types of applications for simulation to increase along with the ability to integrate simulation with existing database and production control systems.

Acknowledgments

The authors appreciate the assistance provided by the International Cooperation Project at Waseda University (91C-7), General Research Funds for the Science and Technology Research Program of the Ministry of Education (C132-268), and for the conduct of the survey, and those who assisted us in the preparation of the questionnaires.

References

1. Morito and Yazaki, "Survey on Current Status for Simulation Usage and Recent Topics on Simulation Languages", Operations Research, Vol. 32, No. 5, 1987

2. Umeda S., "Discrete System Simulation and Its Environment", Measurement and Control, Vol. 30, No. 2, 110-115, 1990.

3. Swain J., "Simulation Software Survey", OR/MS Today, 81-102, October, 1991

4. Law A. and Haider S., "Selecting Simulation Software for Manufacturing Applications: Practical Guidelines & Software Survey", Industrial Engineering, Vol. 21, No. 5, 33-46, May, 1989.

PART 2

Discrete Event Simulation in Japan - State-of-the-art and its Future

Shigeki Umeda

Abstract

This paper describes the current status of discrete event simulation in Japanese industry by an investigation of various field users. The topics covered include the objectives of simulation, types of simulation projects, software selection policies, and others. One of these topics, the "useware" of simulation, is discussed through examples from several application fields. The paper concludes with discussion of the future of simulation technologies in Japan.

1. Introduction

It has been about 30 years since Tocher's first challenge to discrete event simulation. The business computing environment has changed continuously during that time, and has, in recent years, expreineced a rapid down-sizing phenomena. At the same time, the evolution of computer technologies has meant that computing cost is no longer a major obstacle in its implementation. Both of these situations has led to a dramatic increase in the industrial use of simulation on the world-wide scale in this decade. Firms can now resolve various business problems by using discrete event simulation, from long term system's planning/improvement to the short term optimization of control operations. These firms are using a wide range of simulation products [1].

These same phenomena have taken place in Japanese industry [2]. The reason seems to be related to the dramatic reductions in the cost of computer technologies rather than the progress in the simulation technologies themselves. This paper describes the state-of-the-art of simulation practice in Japanese industries, and looks ahead to its future directions.

2. Simulation Projects

2.1 Objectives of Projects

The targets of simulation are rapidly expanding to various fields including the analysis of manufacturing lines, material handling systems, logistics systems, computer systems, and others. Among them, the applications to factory material handling systems such as AGVs, and cranes have increased the most in recent years. In addition, logistics systems such as distribution systems or automated warehousing systems are becoming common targets of simulation as are computer and communication systems (see Table 1, PART 1).

In the past, the main objective of simulation has been the performance evaluation of a planned system, like a manufacturing line. But, in this survey, it has become clear that the applications to daily operations control are increasing.

2.2 Practice of Project

There is a wide range in the types of simulation projects in industry. Many of them are short-term projects (within a few months)) carried out by a small set of restricted people. The project development team is comprised of both an "Industrial Engineering" group and an "Information Systems" group. The field workers often join these development teams. In some cases, the vendors develop the actual simulation models. The majority of the users come from the field workers (see Table 2).

Table 2. Simulation Project Member

	Development members	users
IE Department	21	10
Systems Department	43	20
Field Workers	34	54
Others	15	7

Table 3. Computing Environment

Workstation (WS)	26
PC	19
Mainframe	5
PC & WS	21
Mainframe & PC	6
Mainframe & WS	6
All kinds	10

2.3 Project Scales

There are various project scales. The smallest on is a .3 man-month project, while the largest one is over 3 years. The project scale depends on both the application fields and its objectives. In comparison with the previous survey in 1987, the number of large scale projects has dramatically increased.

Table 4. Simulation Software

Simulation Language only	21
Simulation package only	16
General programming language only	1
Simulation and programming language	15
Simulation language and package	14
All software	23

Table 5. Selection criteria

Modeling capabilities	66
Easy-to-use/easy-to/learn	57
Easy-to-customize	23
Price	15
Vendor support	5
Number of users	3
Others	3

3. Computing Environment

The phenomenon of computer down-sizing is also evident in this survey. More than 90% of the responders indicate that the computer of choice for simulation is either a workstation or a PC. These small computers have benefits because of the low price and the superiority of their man-machine interfaces. Many of them support a graphical user interface (GUI) like windows and icon-based front-end modeling systems.

4. Simulation Userware Requirements

4.1 Software Utilization

Simulation software can be classified into three types: general simulation languages (GPSS, SIMSCRIPT, SIMAN, etc.), simulation packages (SIMFACTORY, AutoMod, WITNESS, etc.) and general programming languages (FORTRAN, C, etc.).

The major advantage of the simulation languages is their modeling generality. Because the models are represented by using abstract modeling constructs like "entity", "transaction", "queue", "resource", special skills are required to build models using these languages. This is also true for the general programming languages and object-oriented programming languages like Smalltalk and C++.

Simulation packages usually provide user-friendly modeling facilities, GUI, and animation facilities which are built on top of a particular language. Most of these packages are designed for domain-specific applications such as manufacturing, communications, and transportation. These software packages enable users to build models in a much shorter amount of time. On the other hand, they are often insufficient to represent some of the detailed features of the target applications.

Several firms use the simulation packages to build models, when these models are of small size systems and and when the packages are sufficient to to capture all of the details (see Table 4).

4.2 Software Selection

Most users indicate that the modeling capability is the most important criterion when they are selecting simulation software. Another important one is an easy-to-learn modeling environment (see Table 5).

Many users have indicated that the ability to customize software is also a key element. General modeling of target systems can be done by using the modeling facilities provided by the software. However, the modeling of more detailed system interactions may require additional capabilities. In these cases, the customization of software may be required in order to describe the details of the target system.

The target systems themselves can impact the required capabilities and complexity of the simulation software. A manufacturing system, for example, can range from a few machines and operators to an FMS, which generally consists of machining centers, load/unload stations, material handling equipment (such as AGVs and stacker cranes), pallets, pallet storage systems, tools, and FMS computers.

4.3 Available Simulation Software in Japan

While there are many commercial simulation software in the world, the available software in Japan are quite a few. Also, in this survey, the software has been limited to several products (see Table 6). Most of the commercial software is imported from the United State and Europe. The most powerful users have developed their own simulation software for internal use.

The reasons that simulation software vendors have not been brought up in Japan are considered as follows:

- The market for simulation software is currently immature
- The simulation users desire vendors to provide careful and continuous support including consultation and instruction. Consequently, vendors' workload is too heavy in the long term.
- The development of simulation software is not profitable in comparison with the market scale and required services.
- Several major user companies own their own internal simulation packages for their own business and internal consultation.

Table 6. Simulation Software in Japan

Simulation Language	SLAM	37
	GPSS	21
	AUTOMOD	16
	SIMAN	9
	SIMSCRIPT	3
	OTHERS	6
Simulation Package	WITNESS	31
	PCMODEL	9
	OTHERS	11

4.4 Simulation Interfaces

Users require the following interface facilities for simulation software:

- support tools for model building
- visualization and easy-to-use interfaces for data analysis
- data translation facilities

Several software packages provide model building tools like graphical model generators and model editors. Most of them are easy to learn and support graphical user interfaces.

Visualization is very important to understand the simulation output data. Several companies use Macintosh computers as a back-end system for presentation. Among the available visualization options, animation facilities are the most popular. These facilities help to present the results of simulation analysis to non-professional people like general managers.

Analysis people often handle the simulation data by PC-based spread sheet software. Simulation input data is directly transferred from either shop floor monitoring systems or production control systems.

4.5 Off-line Simulation

Simulation is a software tool to support decision-making at both the planning stage and the operational stage. Systems integration requires various types of software such as system enablers (utility programs), application enablers (module libraries), databases, and others.

At the planning stage, the following operations are considered:

- Production preparation in CIM
- Design/evaluation
- Performance evaluation/analysis of manufacturing lines
- Verification of tool paths
- System optimization

There are also production support activities such as line design, operational and planning management. In all of these operations and activities, the output analysis and its visualization like animation will be a key element.

4.6 On-line Simulation

At the operational stage, the following functions are candidates for on-line simulation support:

- Production planning/control support
- Scheduling planning/evaluation

On-line simulation requires the integration with a shop floor monitoring system and a link to external data sets. Several manufacturing firms have linked simulation to external applications. The examples of the challenge are as follows.

- To link mainframe computer with workstation/PC through LAN and data converter. Simulation utilizes the output data from the host computers as the input parameters.
- To link workstation with PC through LAN. The statistical analysis is done by using spread sheet software.
- Down-loaded data from Production Planning/Control database to simulation input parameters.
- Generate simulation input parameters directly from process- control computers.

5. Future of Simulation Technology and Applications

The above descriptions depends on the survey of Japanese industrial simulation users. The author, now summarizes the technological trends in the near future.

5.1 Virtual Plant System

"Virtual Plant System" (VPS) is a concept (see Figure 1.) which combines real-time facility monitoring with on-line factory simulation by computer network [3,4]. The implementation of VPS requires manufacturing simulation models of plant information flow as well as material flow.

The monitoring system observes major transactions at each plant layer: such as production orders, vendor activities, WIP transactions, machine break-downs, and others. And the system periodically sends the transaction data to the simulator through a parameter generator.

The planning system must send plant control data to both the actual and virtual plant system. Simulation can react to the same material/information flow in the computer as the actual plant. The computing environment will enable manufacturers to predict the key events in the plant, and support rescheduling operations in real-time.

VPS will be useful to measure system performance at its design stage considering plant operational policies. As a practical application, the author applied this approach to a material flow design problem in a steel plant. The author also demonstrated that using experimental design method during the simulaiton study can dramatically reduce the simulation cost.

5.2 Distributed Simulation

Distributed simulation is a technique to implement simulation by using several independent interconnected processors. This is also effective way to simulate a very large model like a huge plant including several factories. Distributed simulation is a fundamental technique for implementing VPS.

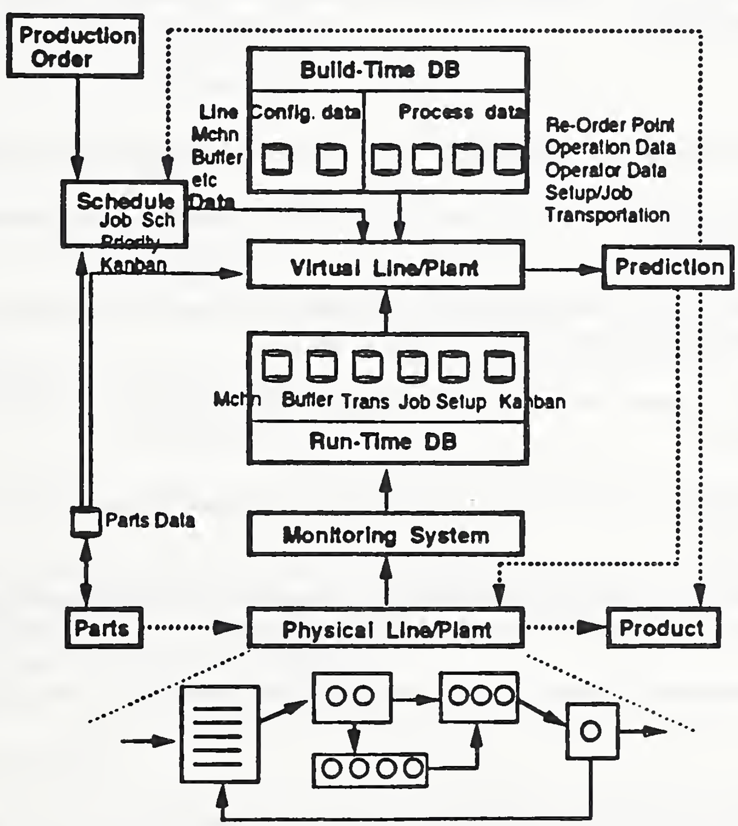

Figure 1. Virtual Plant System Concept

The key to implementing distributed simulation is a synchronization mechanism. The famous method to do this is called the "time-warp" method [5]. The "time-bucket" method [6] has also been proposed as an effective way to implement manufacturing models. In this way, each processor simulates an assigned model for a predetermined interval called a time-bucket, and rolls back to a certain time if some concentration occurs during the time interval.

5.3 Object-Oriented Simulation

Object-oriented modeling methods are currently very popular in many areas of computing. The popularity of this approach has been increasing in those areas associated with systems modeling and management science [7]. The concept of object-oriented modeling was used in a simulation language called "SIMULA" which is also associated with a process-interaction view of discrete event simulation. Possibly as a consequence of this, most of the attempts to take an object-oriented approach within simulation have been associated with a process-based or a process-interaction-based modeling paradigm.

The advantage of object-oriented modeling is that it permits users to utilize previously developed modules, when necessary, to derive new models which are subsequently added on the original models. The key element in this approach is the existence of a library of models. These models should be specific to each application domain: such as manufacturing systems, logistics systems, material handling systems, computer systems, and others. Common libraries are also important. The object-oriented modeling methods can also be applicable to the development of user interface systems.

6. Conclusions

Many users expect future improvements in simulation technology in the following areas: simulation performance, interface facilities for model building and presentation of simulation outputs, integration methodologies into total system.

References

1. Swain J., "Flexible Tools for Modeling", OR/MS Today, 62-78, December, 1993.

2. Umeda S. and Morito S., "State-of-the-Art and Future of DEDS Simulation", Communication of ORSJ, Vol. 38, No. 11, 561-565, 1993.

3. Umeda S., " Manufacturing-Oriented Simulation for Production Management", International Journal of Materials, Production, and Technology, Vol. 7., 278-289, 1992.

4. Umeda S., "Simulation-Based Production Control System in CIM Environment", Production Research, Vol. 93, 353-354, 1993.

5. Lin. Y., "Selection the checkpoint Interval in Time Warp Simulation, Proceedings of the 7th Workshop of PADS93, 3-10, 1993.

6. Fujii S. and Hirano M., "A Basic Study of Distributed Simulation Model of Virtual Manufacturing Manufacturing System Under CIM Environment", Production Research, Vol. 93, 381-382, 1993.

7. Proceedings of International Conference on Project-Oriented Modeling, May, 1992.

PART 3

In this part of the report, we provide an analysis of the state-of-the-art of research in simulation. This analysis is provide by five US researchers - Dr. Jerry Banks, Georgia Tech; Dr. Yuehwern Yih, Purdue University; Dr. Wayne Davis, University of Illinois; Dr, Hank Grant Oklahoma University; and, Dr. Leslie Interrante, University of Alabama. These researchers attended the conference on New Directions in Simulation for Manucaturing and Communications held in Tokyo August 1-2, 1994. What follows is a summary of their reactions to the papers presented at the conference and their conservations with Japanese participants in the conference. Many papers are referenced . The papers can be found in the proceedings which are included as a separate document.

1. Who are the players?

The field of simulation is growing. However, no universities are teaching simulation as a course by itself. Rather, simulation is being taught within a course in operations research. As evidence of the prominence of simulation within the academic community, the committee that organized the conference was largely made up of university faculty. The plans for the conference were underway for four years.

The major universities involved in simulation (and their areas of concern) include

Waseda Universities in both research and education
University of Tokyo in both research and education
Aoyama and Musashi Universities in education only

As for industry, the simulation players can best be described by industry sector:

Steel	Shin-Nippon Steel
	NKK Co.
	Kawasaki Steel
Automotive	Toyota
	Nissan
	Honda
	Matsuda
	Mitsubishi
Electric	Too numerous to list, virtually all of the big names
Eng. Cons.	Sumitomo
	Toyo Engineering
	Chiyoda
Heavy Industry	Mitsubishi

There are only two Japanese firms that market and sell simulation products, and their share of the market is very small. The products are for Japanese implementation only are:

Komatsu Co.	Product - Kosmolator
IBM Japan	Product - MASSIM

2. What are the tools?

The perceived high cost of simulation software has restricted the commercially available simulation tools within Japanese universities. Commonly used tools in an academic setting are the following: SLAM, SIMAN, and GPSS/H

The most prevalent software in industry is SLAM (Pritsker Corporation says that 500 packages are installed in Japan). But there are others including the following: WITNESS, SIMAN, PCModel, and AutoMod. PCModel is a product that does not have a large installed base in the US. However, in Japan it is marketed by Shin-Nippon Steel leading to a few, but not many, sales.

The vendors of simulation software include the following:

Vendor	Agent for	Selling
Chiyoda Corp.	AutoSimulations, Inc.	AutoMod AutoSched
Kozo Keikaku Eng.	Pritsker Corp.	SLAMSYSTEM FACTOR/AIM
Nippon T&T		INSYDE
Mitsubishi Hvy. Ind.	Systems Modeling Corp.	ARENA SIMAN/Cinema
CRC Research Inst.	AT&T ISTELL	WITNESS
Mitsubishi Corp.	AesopBmbH	SIMPLE++
Nippon Steel (Info & Communications Systems)	SimSoft Inc.	PCModel CADMotion
Seki Technotron Corp.	CACI Products C.	SIMSCRIPT II.5 MODSIM II OMNET III

3. Overview of the New Directions in Simulation Conference

Generally speaking, the conference included a wide variety of researchers from Japan and the United States as well as several countries around the world. Other countries represented by authors or attendees included Germany, Korea, Chile, Canada, Israel Italy, Brazil, Singapore, Thailand, Sweden, and Russia. The conference was organized around a variety of sessions on topic of importance in Simulation research and practice. Each session is discussed below along with a summary of the information provided.

The topics address in the conference fall into the following topics:

- Invited Papers,
- State of the Art Papers,
- Manufacturing Systems,
- Other Systems,
- Probability, Statistics, and Analysis, and
- Modeling Technology.

3.1 Invited papers

Several papers were presented written by leading international experts in Simulation. These papers set the tone for the conference and covered some of the most important areas of simulation research and practice. Topics addressed included: Successful Simulation; Design of Flexible Manufacturing Systems; Fast Parallel Simulation; Comparing stochastic Systems; Random Optimization; Simulation Modeling in Reengineering; Trace Driven Simulation; and Simulation of Semiconductor Lines.

Missing from this set of topics were papers on such issues as new language design, simulation tools for corporate management, and the implementation of newly developed theoretical techniques in simulation languages.

3.2 State of the Art

The papers in the State of the Art session addressed three different topics: the future of discrete event simulation in Japan, the consensus process in simulation projects, and a manufacturing model using scene transition nets. These are important topics and represent some of the leading edge developments and issues in simulation application and growth.

3.3 Manufacturing Systems

This group included eight separate sessions at the conference and represented 24 separate papers. A variety of industry applications were discussed relative to the application of simulation technology. These sessions provided much food for thought for the application of simulation in the manufacturing environments of the present and the future. The following will provide a brief summary of the topics covered in each session.

3.4 Innovative Applications in Manufacturing

This session covered new application of simulation in manufacturing, including bottleneck management via simulation, effects of high quality information in receiving departments, and JIP production system efficiency.

3.5 Flexible Manufacturing System I and II

These two sessions Focused on FMS applications and provided six papers in this area. Topics included simulated annealing applications, scheduling, AGV scheduling, decision rules for job shop scheduling, Coordination of FMS, and performance analysis.

3.6 Virtual Factory

This session concentrated on the concept of distributed production systems and the use of simulation in modeling and managing these systems. Topics included Distributed manufacturing and enterprise integration.

3.7 Manufacturing Applications

This session provided a variety of application in manufacturing systems. They included a large scale simulation study, job shop simulation, and lead time reduction studies.

Semiconductor Manufacturing

This session provided papers which addressed issues specifically of interest in semiconductor simulation. The topics included finite capacity planning, job shop simulation, and test of production control policies in wafer fabrication.

Simulators for Manufacturing

This session was concerned with the selection and use of tools for manufacturing system simulation. The topics included line balancing in assembly facilities, selection simulation software for manufacturing, and production system design.

Methodology in Manufacturing

This session provided discussion of a variety of tools which could be used for analysis of manufacturing systems based on simulation technology. They included object oriented simulation tools, generic simulation in the electronics industry, and planning systems based on simulation.

3.8 Other applications Systems

In addition to Manufacturing Systems, a variety of other systems were discussed at the conference, considering their use of simulation. This group included seven session and 21 papers. While somewhat limited, due to the time constraints of the conference, these topics represent a good overview of the use of simulation in non-manufacturing systems.

Communication Systems Performance

This session focused on communication systems. It included papers on LAN simulation, circuit switched telecommunications networks, and performance evaluation of a connectionless data server.

Computer System Performance

The papers in this session focused on improving the performance of computer systems. Topics included dynamic load sharing, real-time database performance modeling, and scalability of loading sharing policies.

Communications Networks

These papers were concerned with network systems and their performance evaluation. They included overload control analysis, adaptive routing in networks, and reliability in disaster simulation.

Transportation I and II

The papers in these two session were concerned with the improvement of performance in transportation systems. Topics discussed included analysis of guide way transit systems in airports, pedestrian traffic flow, train traffic, high speed railway traffic demand forecasting, and container port operations.

Logistics

This session included two application of logistics analysis: Shipyard logistics and design of a production ordering system for a global system.

Innovative Applications

This session included three application papers by simulation leaders. The topics covered the expanded usage of simulation, enterprise wide simulation, and hypertext based simulation.

3.9 Probability, Statistics and Analysis

This group of sessions focused on provided a discussion of a variety of topics in the statistical aspects of simulation and the analysis and optimization of simulated system performance. There were five sessions included and comprised 15 papers in this area. A discussion of each of the sessions follows:

Random Number Generation I and II

These two session focused on random number generation issues. The discussion concerned the generation and quality of random number sequences. They included accuracy assessment, sequences based on Pascal's triangle, and quality improvement, and the AEI algorithm to generate normal random variates.

Statistical Methods

This session addressed a variety of statistical methods. They include importance sampling, and relative differences analysis.

Output Analysis

This session was concerned with the analysis of simulation model output. Topics addressed included the use of Procrustes Analysis Method, Regenerative Bootstrap methods, and precision reporting methods.

3.10 Optimization

This session was concerned with the optimization of systems using simulation models. Topics included optimal configuration of systems using simulation-optimization, perturbation analysis, and multilevel simulation of manufacturing systems.

3.11 Modeling Technology

This group of sessions was concerned with methodologies for modeling systems. There were seven session included in this group and represented 21 papers.

Object Oriented Modeling

This session presented several object oriented modeling approaches. Included were an approach for modeling manufacturing systems, flexible modeling of transportation systems, and AGVTALK: an object
oriented simulation tool for AGV systems.

Object Oriented Simulators

This session presented three languages for object oriented modeling: SIMPLE++, DEVS, and PASIMT++.

Petri Nets

This session provided three examples of the application of Petri net theory in the analysis of systems. They included simulation based scheduling, semantics of Petri Net Models, and modeling of AGV networks.

Artificial Intelligence

This session provided and introduction to Artificial Intelligence techniques using in the simulation of systems. Topics included knowledge acquisition, a knowledge based interface to simulation models, and a rule based simulation for steel manufacturing processes.

Modeling Methodology

This session provided a mix of experimental and application based papers concerned with different approaches to simulation modeling. They included time separation and level of abstraction, modeling
discrete event systems, and an application of simulation modeling in product costing.

Decision Making

This session provided two papers concerned with decision making in simulation in general and a specific application to production scheduling.

Combined Methods

This session presented three application of combining techniques in simulation analysis. They included simulating parallel computation, structural modeling, and discrete continuous scheduling problems.

3.12 Conclusions

The quality of the organization of the conference was excellent. Along with providing an excellent conference, Dr. Morito and his colleagues made the trip to Japan and the stay there effortless. The quality of the presentations was also very good. Generally, the conference was more focused on the application of simulation in a variety of ways than on theoretical developments in simulation. While these presentations included much of use in the development of simulation theory, there was not time to integrate this information.

In conclusion, the conference provided a high quality and worthwhile experience for all attendees. It would be worthwhile continuing this conference in Japan in future years. Perhaps a joint organizing committee could be assembled from Japan, the United States, and other countries. The conference provided a broad base of topics and would have been of interest to both the simulation practitioner as well as the simulation theory developer. In a relatively short amount of time, a large variety of topics were covered in depth and effectively presented to the conference attendees

4. Applications of simulation in Japan

Based on the documents presented in the Proceedings of New Directions in Simulation for Manufacturing and Communications (SIM94), there are two major areas of simulation applications in Japanese industry: manufacturing and communications. In manufacturing, the simulation applications include daily operations control, evaluation of manufacturing systems, material handling, and logistics systems such as distribution systems or automatic warehouses. There are various projects in computer systems, communication systems, and traffic systems. According to the survey paper described in PART 2, most of those projects are short-term and are often conducted by industrial engineering groups and information system groups. The scale of the projects range from 0.3 man-month to 36 man-months.

4.1 Simulation applications in manufacturing

Katayama et al. proposed a design and improvement methodology of work formation for shop floor production system involving handicapped workers. A case study was conducted in a factory producing funeral outfits to verify the effectiveness of the proposed method.

Arai et al. use real-time simulation to support a study of new distribution of role of CAD/CAM/FA systems in the future manufacturing systems. Fujii et al. proposed a distributed simulation model for

virtual manufacturing as a tool to evaluate the performance of a large and complex manufacturing system under CIM environment from the design and/or decision making viewpoint.
Muro and Terano proposed a rule-based simulation technique for an automated transportation system in a steel manufacturing process. The knowledge base is refined by a classifier system while the simulation system is working.

Rajasekera and Urasa applied spread sheet simulation in determining product cost, especially in electronic manufacturing. The simulation was used to help in understanding the critical parameters of the cost equation. An example of video device was provided.

Koshikawa and Tanaka from Chiyoda Corporation studied the paint facilities in an automobile plant using simulation. AutoMod, a discrete simulation package with 3-dimensional animation, was used in this study. This paper described the process of simulation modeling, optimization of the layout and transportation system, lead time estimation, the study of impact of machine breakdown and the changing of repairing rate.

Yazaki in Sony Corporation presented an example of using simulation to understand the lead-time reduction activities, and consequently to reduce manufacturing lead-time. In this study SLAM-II is used for the simulation. The manufacturing lead-time is reduced from 4 days to 2.5 days.

Tanaka from Chiyoda Corporation presented an application of discrete event simulation for line balancing and task assignment for operators in final assembly shops in automotive plants. The experiences gained from the simulation process have helped to reduce engineering man hour reduction and yield high quality planning for line layout.

Fukuda et al. from three different corporations and one research institute presented a paper to describe an integrated environment for production system simulations. This paper addresses the issue that the designers need to rewrite the simulation model several times through the system design process. An integrated environment was proposed to overcome this problem. The prototype of this environment was developed by Intelligent Pads, GPSS/H, and PROOF.

Fujimoto and Yasuda presented a simulation-based study of a four-level job shop scheduling approach where scheduling decision rule sets are used to determine the job releasing, the next visiting machine, the job dispatching and the job pulling.

Hirakawa proposed a quasi Monte-Carlo method to analyze complex flexible manufacturing systems. The proposed method is similar to the conventional Monte-Carlo simulation but with greater precision. This method is tested on a queuing network problem.

Nakano et al. from Toyota Central R&D Labs proposed a high-fidelity, easy-to-use object-oriented manufacturing simulator ROPSII. An assembly automation system in an automobile plant was used to show the effectiveness of the proposed simulator.

Inoue and Fuyuki proposed a hybrid method of forward and backward simulation methods to make production schedules. An interactive simulation based planner's tools-system is further developed as a supporting tool of a scheduling activity. The proposed method and system was applied to a real production system in Sumitomo Metal Industries, Ltd. to demonstrate its effectiveness.

4.2 Simulation applications in communications

To predict and enhance the performance of local area network (LAN) systems, Kobayashi et al. at Toshiba Corporation developed a simulator based on the combination of object-oriented programming and an event-driven model. This method was applied to simulate ADMAP-100F, a process-control LAN, and it showed that the proposed method enhanced the flexibility of network simulation compared to the traditional discrete-event simulation.

Hasegawa and Inoue at Nippon Telegraph and Telephone Corporation (NTT) developed a network simulator with a parallel simulation algorithm based on a model of the circuit switched telecommunications network provided by NTT. This simulator is used to support the network operators to control and manage the traffic flow in order to maintain service quality. Zhang et al. and Ashihara et al. use simulation to study the loading-sharing strategies of communication network in distributed systems.

Kawahara et al. from NTT used simulation for the analysis of overload control for the Intelligent Network (IN), a proposed future communication network. A network simulator, called the IN Simulator, was developed to evaluate the overload control characteristics under various overload traffic patterns.

Takeo and Masahiro from NTT simulated disasters in the telecommunication network to evaluate its reliability. A disaster is characterized by the event's location, sphere of influence, and magnitude of destruction. This disaster simulation helped to reveal vulnerable points in telecommunication networks and to evaluate the effects of route diversity. The simulation results are useful for making contingency plans for the public service telephone network.

Nakamura and Hibino at Mitsubishi applied discrete event simulation to analyze the stream of pedestrian traffic that occurs on major urban center of sidewalks and intersections. The simulation model is used to study the impact of a small-scale construction plan for an elevated sidewalks in a local area which is proposed by government to alleviate congested conditions on a narrow sidewalk due to the lack of capacity.

Cheng et al. proposed a new approach that combines the knowledge-based system, traditional mathematical programming, and simulation to study the long distance railway line. The proposed simulation method can be used to analyze, optimize, and confirm the correctness of traffic schedule in short time and meet the real time demands. Takahashi from Mitsubishi proposed a discrete event simulation approach to forecast demand for a high-speed railway.

5. Methodology Research

5.1 Output Analysis and Statistical Methods

There was a single Japanese paper on Importance Sampling presented by Takahazu Sakai and Haruo Ogiwara., There were three additional contributions from Korea by Lee, Park, and Moon, Kim, and Hong and one paper from Taiwan by Shih and Song . It should be noted that this was an area also covered by tutorials given by American authors at the conference.

5.2 Generation of Random Numbers

Here, Hirotaka Sakasegawa presented the only Japanese paper which developed a new algorithm for generating normally distributed random numbers. The primary claim for the new model was an increase in computation speed.

5.3 Optimization

There were no Japanese papers explicitly addressing theoretical development under the optimization section. However, Morito and Lee did apply the technique of simulation annealing to select dispatching rules for the a FMS.

5.4 Virtual Factory

The paper by Arai, Uchiyama, and Sea-Tang is of particular interest as it attempts to integrate Computer-Aided Design, Computer-Aided Manufacturing, and Facility Analysis. The authors talk about the integration of these functions denoting which functions can be performed off-line and which must be performed on-line. They establish the need for real-time simulation, but it must be noted that their references in this subject are somewhat dated. They do not provide explicit algorithms for implementing design and apparently no system has yet been implemented.

The second paper by Fuji, Hirashima, and Tsunoda is more focused upon executing simulations for large-scale systems through the distributed simulation of its subsystems. Again the concern for speed arises from the need to perform real-time simulations. Their basic algorithm for distributing the simulation is the time bucket method. They provide a modified version of SLAM II code which they employ for describing the model for their distributed simulator.

A third paper by Yoo, Park, and Baik from Korea discusses the simulation of real-time transactions for database systems in flexible manufacturing. Hence, this paper addresses real-time simulation.

5.5 Distributed Simulation

In addition to the Fuji et al. paper discussed under virtual manufacturing, there is another Japanese paper by Hasegawa and Inoue which discusses the application of parallel simulation to model telecommunication networks. The authors exploit the fact that several events occurring in this system can be processed in parallel, and they develop a special synchronization algorithm to distribute the simulation. They also provide experimental results.

5.6 Object-Oriented Modeling

The paper by Nakano, Sugiura, Tanaka and Kuno discusses a new object-oriented simulator which they developed called ROSL II which is an extension of a robotic simulator termed ROPL II. ROSL II employs yet another object-oriented simulation language (in this case, SIM++) to allow the user to enter the model using C-like statements. The paper provides detailed discussions of their classes and instance specifications.

Professor Kim of Korea has developed a C++ implementation of the DEVS-Scheme language developed by Professor Bernard Ziegler, which he claims is far faster.

5.7 Petri Networks

I found the paper by the Japanese authors Kawada, Kawata, and Watanabe to be the most interesting paper at the conference. They discuss a new technology--scene transition nets--which they assert is an extension of Petri nets. I am not certain, however, that it is all that different from colored Petri nets. The major feature of this work is that they permit detailed simulation of the continuous state processes which often determine the time required for a transition. That is, they are integrating the simulation of the shop floor with a detailed simulation of the processes.

A second Japanese paper by Shiizuka and Suzuki on Petri networks proved disappointing. The authors defined several different Petri nets for controlling transactions in a Petri net. I was interested in using their figures in my classroom. However, on closer analysis, I found several errors in their published figures. It should be noted that the figures they used in their presentation differed form the published figures, but they did not make note of this discrepancy.

5.8 Conclusion

I believe that the Japanese are devoting less effort to the traditional areas of statistical analysis, much of which is not applicable to the real-time concerns. Instead, they are pushing toward virtual manufacturing including an increased capability in real-time simulation and scheduling. This research includes the development of an integrated framework for virtual manufacturing and the development of technologies for distributed simulation needed to support the real-time simulation requirements. Furthermore, they have recognized the need for integrating real-time process simulation with real-time shop floor simulation.

These technologies are critical to supporting flexible/agile manufacturing. The Japanese have recognized this need. My conclusion based upon Professor Umeda's survey is that the Japanese recognize important future methodologies, but little research on these topics is being addressed. However, after reading the Japanese contributions to this conference, I believe that significant Japanese research is addressing these methodologies.

6. Research trends in Japan

In total, 50 papers were examined in order to determine the state of the art in Japan. Thirty-four of the papers were from New Directions in Simulation for Manufacturing and Communications, the proceedings of the Japanese simulation conference which was attended. Of the 34 papers, the paper by Shikegi [16] was a survey paper. Of the remaining 33 papers, 12 were authored by employees of industrial [20-22, 25, 35-40, 43, 47] firms, 18 [17, 18, 23, 26-31, 33-34, 41-42, 45-46, 47-48] were authored by employees of academic institutions, and three [19,24,32] were jointly authored by industry and academia. The papers were further classified by the type of simulation. Of the papers that mentioned a specific type of simulation, nine were discrete-event simulation [18-20, 25, 27, 35, 39, 40, 43], one was Monte-Carlo simulation [46], three were object-oriented simulation [17, 20, 47] , and one [33] was static (spreadsheet) simulation.

6.1 General statistics from the Tokyo conference

Many of the papers described the combination of simulation with Operations Research techniques or Artificial Intelligence techniques. Five of the papers combined simulation analysis with Operations Research techniques, including math programming, queuing analysis, heuristic dispatch rules, and other analyses [18, 19, 23, 42, 46]. Ten of the papers combined simulation analysis with Artificial Intelligence techniques [17, 20-21, 23-24, 27, 32, 42, 44, 47] , including genetic algorithms, simulated annealing, machine learning, knowledge-based systems, distributed and parallel models, causality, and object-oriented programming. It is clear that the integration of simulation analysis with other types of analyses is common practice for applications development in Japan.

The papers were classified according to the type of task accomplished via the simulation. Eight of the papers described planning and scheduling tasks [19, 23, 30, 40, 42, 45, 48, 49], and eight of the papers described distributed network-type tasks [20, 21, 25, 28, 29, 37, 38, 42]. Material handling was the topic of four papers [17, 24, 32, 35], and three of the papers described systems for assisting in simulation model development [31, 41, 47]. Two papers involved layout problems [18, 35], two papers described random variate generation [22, 26], and one paper was focused on product cost estimation [33].

Most of the papers described application development as opposed to basic research in simulation. The application-oriented papers were subdivided according to the area of application. Four papers involved telecommunications applications [21, 28, 37, 38, FMS applications were the focus of three papers [24, 27, 46], manufacturing automation was described in three papers [35, 40, 47], three papers described transportation problems [25, 42, 43], and one paper each was related to semiconductor manufacture [39], apparel manufacture [18], and the steel industry [32].

6. 2 Some thoughts on Shigeki Umeda's paper

Shigeki [16] conducted a survey of Japanese industries which are developers and users of discrete-event simulation. He claims that Japanese industry follows the general trends of downsizing in computing environments and dramatic increase in the number of simulation applications. Among the Japanese firms surveyed, simulation applications include (in order of decreasing frequency of application) manufacturing lines, material handling systems, logistic systems, automated warehousing, computer systems, traffic systems, and communication systems. There has been a recent increase in material handling applications. Daily operational factory control applications have also increased.

Shigeki claims that many of the simulation projects are short-term, with a duration of a few months. Members from the firms' systems engineering departments play the greatest role in simulation development studies, although industrial engineering and field workers are also involved. Large-scale projects have dramatically increased over the last six or seven years. Over 90 percent of the survey respondents indicated that they use either a workstation or PC-sized machine for simulation work. The majority of developers surveyed use either simulation languages or simulation packages to develop models. General-purpose programming languages are quite often used in conjunction with a simulation language or package, but only one respondent uses a general-purpose language alone for such work.

The paper states that modeling capability is the most critical selection criteria for simulation software, followed by ease of use/learning, ease of customization, and price. Most commercial simulation software is imported from the United States and European countries. Some firms have developed their own simulation software for internal use. SLAM is the most popular simulation language among those surveyed, followed by GPSS, AutoMod, and SIMAN. Popular simulation packages include Witness and PCModel among others. Desired interface facilities include model-building support, visualization and ease of use for data analysis, and data translation capabilities. Many applications employ post-processing of data via a spreadsheet analysis.

Off-line simulation applications for planning include CIM production preparation, design/evaluation, manufacturing line performance evaluation, system integration verification, and system optimization. On-line simulation applications for operational analyses include production planning, control, and scheduling. Some firms have linked simulations to external applications, including:

1. receipt of output from host computers as input parameters,
2. post-simulation statistical analysis via a spreadsheet,
3. downloading of data from production planning/control as input parameters, and
4. generation of simulation input parameters directly from process control computers.

It is important to note that little information was given in [16] regarding the questions asked on the survey, the target population, the respondents, or other data which would be valuable in the interpretation of survey results.

6.3 Simulation and JIT production systems

In [12], Corbett and Yucesan review the recent literature on JIT production systems. They focus on model-based approaches in studying pull systems via simulation. In particular, they were interested in a problem in implementation and control related to JIT systems referred to as the operational control problem: implementation of the kanban system to control the interaction between production and inventory levels. They state that the literature is largely case-oriented, with particular focus on high volume, repetitive manufacturing environments. The examined models include both deterministic and stochastic ones. Stochastic models include analytic models (Markov processes, queuing models) and numerical approaches (queuing approximations and computer simulation). Deterministic models include linear programming and dynamic programming.

Corbett and Yucesan claim that the published research relies heavily on computer simulation. Factors which were studied include the impact of production stoppages, inventory policies, variability in supply and/or processing rates, increase in capacity, control mechanisms, varying environmental conditions, and sequencing rules. Measures of performance of interest include throughput, shortages, and idle time. Identified flaws in the published simulation studies include a lack of the following: justification for models of randomness, verification and model validation, attention to experimental conditions (transient period, run length, and number of replications), and description of statistical output analysis techniques employed in the study.

The paper states that simulation is recognized as the most powerful tool in analyzing JIT practice because of the complexity of such systems. The problem of limited generalizability of simulation studies is a problem, however. Consequently, it has been difficult to answer general questions related to: the evaluation of JIT performance, the factors most critical to JIT success, the types of production systems in which JIT will perform well, and how to transition from a push to a pull system. It is concluded that the key to improving JIT system performance is the adjustment of environmental factors rather than the kanban system.

6. 4 A brief review of Japanese Winter Simulation Conference papers 1991-1993

The remaining 15 papers which were reviewed were from the Proceedings of the Winter Simulation Conference over the last three years (1991, 1992, and 1993). The next section contains a brief description of each of these papers. Of the 15 papers, one paper was not authored by a Japanese person, but it was a review and critique of research related to the Just-In-Time Kanban system, a technique which originated in Japan. The other 14 papers had Japanese authors. There was some overlap in both authorship and content between the WSC papers and the Japanese simulation conference papers (the first group described above).

Seven of the 14 papers were authored by industry employees [1, 2, 4, 9, 10, 11, 15], three were authored by members of academic institutions [4, 6, 14], and four were jointly authored by industry and academia [3, 5, 8, 13]. Of the papers that mentioned a specific type of simulation, eight described discrete-event simulation [1, 3, 4, 6, 7, 8, 11, 13] and one described object-oriented simulation [2]. The combination of simulation and Artificial Intelligence was described in four papers [2, 10, 13, 15]. The papers were classified according to task. Eight of the papers mentioned planning and scheduling tasks [1, 3, 6, 8, 9, 10, 13, 15], two of the papers described material handling tasks [4, 14], and one paper each was devoted to the tasks of simulation modeling [2] and random variate generation [5]. As was true of the first group of paper, most of the papers in this group described applications work as opposed to basic research. The applications included the steel industry [2], FMS [3, 8, 13], semiconductors [7, 11], and telecommunications [9, 10, 15].

Aoki, et al. [1] developed a scheduling system for the factory floor which addresses the recent trend in increased production complexity arising from product mix issues. The scheduler is based on a heuristic optimization algorithm and a discrete-event simulation. Two features of the scheduler include high-speed scheduling via local optimization related to the shop floor model and simple dispatching rules, and a multiple-objective scheduling algorithm. The scheduler has been used for daily scheduling in a PCB assembly shop at NEC for a year. It is claimed that the system is about twenty times faster than the manual scheduling process.

Muro, et al. [2] built a simulation system based on the KEE expert system shell (IntelliCorp) and SimKit (IntelliCorp). Their system, SSS, is based on object-oriented programming and provides steel plant engineers with an environment for building computer simulation models. SSS is installed in three major locations of Kawasaki Steel Corporation.

Morito, et al. [3] designed a simulation model to analyze Mazatrol FMS systems (Yamazaki Mazuk, Inc.). The purpose of the model is to study the effects of various types of flexibility (i.e., routing flexibility based on configuration) on FMS performance. The model was developed in cooperation with Yamazaki Mazuk, Inc.

Takakuwa [4] employed discrete-event simulation to study operational instructions and design policies for implementing computer-aided car systems for low-volume material handling. Optimization analysis was performed to determine the number of carts under multiple criteria: minimum time, minimum cost, and maximum profit.

Tezuka and Fushimi [5] developed a random variate generation technique which considers GFSR sequences with low discrepancies. The discrepancies are produced by a recurrence relation with a characteristic polynomial which is a primitive pentanomial. Each term can be generated via only three bitwise exclusive-or operations. The low discrepancy points were applied to multiple integration problems.

Umeda [6] developed simulation software to support manufacturing systems planning and operational control. The software was verified by applying it to a practical manufacturing line. An event-search algorithm is employed to improve simulation performance by handling simultaneous state events. The modeling language directly represents production-order methods in models. Both push-type, pull-type, and hybrid transportation logic can be modeled. The simulator is a software product of IBM Japan Ltd.

Fujihara and Yoneda [7] view discrete-event simulation as a form of language processing. They developed a simulator which proceeds by sequentially rewriting the state description. It was applied to the on-line simulation of semiconductor fabs. The fabs present state is downloaded from the fab's database. The state description is stored in a database with a splay tree (reorganizing binary search tree) algorithm. The purpose of the simulator is for lotwise trace prediction in day-to-day fab operation. The simulation is deterministic. It is claimed that relatively large models can be handled with this system.

Morito, et al. [8] give an update of their work described in [3]. The new analysis focuses on machine utilization and sojourn time rather than makespan. The effects of routing flexibility and of the number of operations and pallets are examined. Increased routing flexibility achieved by having several alternative machines leads to improved machine utilization and reduced sojourn time. The simulation model is based on the Mazatrol Corporation FMS.

Ozeki and Ikeuchi [9] created a new method of evaluating the customer service quality for a proposed service provisioning process in the telecommunications field. Work-flow-dependent response time is evaluated via computer simulation. This paper represents one of a few attempts to modify the work flow as a whole in telecommunications applications, rather than focus on an individual work process or processes. The model is based on the concept of "measure of customer service quality (MOSQ)" which the authors developed.

Hasegawa and Inoue [10] developed an Intelligent Decision Support System (IDSS) to improve support for managing and administrating nation-wide telecommunication networks. A network simulation is at the heart of IDSS, which represents a virtual nation-wide telecommunication network. It is difficult to forecast service demand and traffic patterns in such networks. The purpose of IDSS is to aid in the application of advanced control techniques such as routing control, congestion control, and network-facility assignment control. Parallel processing is employed in the network simulator mechanism to achieve high-speed simulation of large networks. Additional capability exists in that empirical knowledge is stored in network operation knowledge bases. IDSS is currently under development.

Nakamura, et al. [11] created a discrete-event simulation system, SEMALIS, to handle complicated lot processing and equipment failures in a semiconductor manufacturing line. Turnaround time and throughput are evaluated when using continuous processing, time-critical express lot processing, and some line operations for efficient lot processing.

Morito, et al. [13] developed a simulation-optimization approach for use with a detailed simulator for a module-type commercial FMS. The objective was to find an appropriate dispatching priority scheme which minimizes the total tardiness. The underlying algorithm combines simulated annealing and simulation. It is compared with standard dispatching rules. Results indicate that workload-based dispatching rules such as SPT work well on a consistent basis.

Takakuwa [14] considered the efficiency of looped-truck Automated Guided Vehicle Systems with an automated warehouse including conveyors and an AS/RS. Factors such as location, number of vehicles, the amount and direction of conveyors, and buffer sizes were analyzed. The primary measure of effectiveness was cost, and the secondary measure was efficiency. A sensitivity analysis was performed. One of the goals of the analysis was to determine the appropriate number of AGVs for the system.

Hasegawa and Inoue [15] developed a parallel-event simulation for modeling a circuit-switched telecommunications network. A specific number of serial events are processed in parallel and some events are reprocessed based on information regarding data dependencies. The checking of data dependencies among events obviates causality errors, thus insuring a result of the same quality as that of a conventional, sequential simulation in a shorter time period. The simulation also provides a way to recover from
scheduling errors.

6.5 Conclusions

Several general conclusions are drawn from the paper review regarding the state of the art in simulation in Japan. The large number of industry-authored papers and applications-oriented papers seems to suggest that simulation is much more prevalent in the industry laboratories and systems engineering departments than in academic institutions. Most of the industry-authored papers described applications that are currently in use. This is true of many of the academic- and jointly-authored papers as well.

There seems to be a large amount of work in combining simulation analysis with both OR and AI analyses, with the bulk of the combined-analysis papers describing simulation-AI integration. The telecommunications industry seems to be leading in this thrust. A caveat applies here: the surveyed papers may not be truly representative of the simulation work in Japan in total.

The findings of a Japan Technology Evaluation Center (JTEC) team tasked with investigating Japanese knowledge-based systems development in 1991 are given in Feigenbaum, et al. [50]. Many of their conclusions apply to simulation as well. In general, Japanese computer manufacturers (such as Hitashi, Toshiba, and NEC) play a large part in simulation application development. The systems engineering department of the firm is typically the focus of application development, with assistance from industrial engineering and field workers. One advantage of this approach is to ease the integration of simulation modeling with other information technology such as existing databases and MIS applications. It appears that more applications of simulation to heavy industry, developed by the particular industry, exist in Japan. The volume of simulation-related research in Japan, however, is considerably lower than that in the United States.

The rate of increase of simulation applications for industry in Japan seems to be growing rapidly. More simulation applications are developed in-house, and very few are contracted to outside firms. Japanese companies seem to have more tightly-coupled research and development, product development, and operations departments or divisions [50], which eases simulation application development considerably. The Japanese tend to measure the payoff of a particular application at the system level rather than the component level. Although this technique gives less information regarding the simulation alone, more information is provided regarding the contribution of the total software application when the simulation is an embedded component of a larger system.

The industrial laboratories of large companies in Japan perform basic research and advanced development in a number of areas including simulation. For example [50], Toshiba has five research laboratories that conduct long-range (5-10 years) research in such areas as computer hardware, manufacturing, and software. Toshiba also has eight development laboratories for mid-term research (3-5 years). In 1991, Toshiba spent 8.2 percent of its annual net sales (approximately $22.9 billion) on research. Work in such laboratories seems to be tightly coupled with application or product development. Although many new ideas originate in the United States and Europe, the Japanese can rapidly develop the technology and transfer it into applications [50].

7. The Future of Simulation in Japan

Shigeki [16] points to several near-future technological trends in Japan with regard to simulation. One is the notion of a Virtual Plant System (VPS), which includes both on-line factory simulation and real-time monitoring. Both plant information flow and material flow are considered. As part of the integrated system, the planning module sends plant control data to both the actual plant and the virtual (simulated) plant. Manufacturers can use such a computing environment to predict the key events in a plant and to support rescheduling operations in real time.

Another trend is that of distributed simulation. The key hurdle in this area is synchronization. Object-oriented modeling seems to be on the increase. Several small OOP-based modeling libraries are mentioned in the papers, and the development of such libraries is expected to increase. In general, Shigeki contends that improved simulation performance, better interfaces for model building and presentation of output, and integration of varied methodologies into the total system will be trends for the future in Japan.

The large number of industry-authored papers surveyed seems to indicate that much of the applications development is actually developed and used by industry. Several papers indicated that simulation performance and its contribution to the firm were being measured. The results were fed back to the simulation developers for the development of improvements in the existing systems. Such a dynamic feedback loop should lead to a greater reliability and higher return on simulation development projects. The ownership of the projects by the firms' systems engineering departments implies a higher degree of commitment to reliance on the results of simulation projects.

The Japanese are moving toward open, client-server architectures, as in the United States [50]. Several related ongoing research projects and future trends are likely to affect the future of computing in Japan [50]. The Japanese are emerging as leader in fuzzy logic (e.g., the LIFE project funded by MITI, 1990) and massively parallel symbolic computing (e.g., the ICOT project funded over the last 13 years by MITI). Industry and government participation in large, long-term research projects of this type serve as the basis for much research in Japan. There tends to be a tighter coupling between research and applications in such projects.

References

1. Aoki, T.; Nakayama, S.; Yamamoto, M.; Hashimoto, M.; and J. Tanaka. "Combinatorial scheduler: simulation and optimization algorithm," Proceedings of the 1991 Winter Simulation Conference, B. Nelson, W. Kelton, and G. Clark, eds., 280-288.

2. Muro, Z.; Yanagihara, N.; and H. Fujimoto. "Super simulation shell for plants," Proceedings of the 1991 Winter Simulation Conference, B. Nelson, W. Kelton, and G. Clark, eds., 289-293.

3. Morito, S.; Takano, T.; Mizukawa, H.; and K. Mizoguchi. "Design and analysis of a flexible manufacturing system with simulation - effects of flexibility on FMS performance," Proceedings of the 1991 Winter Simulation Conference, B. Nelson, W. Kelton and G. Clark, eds., 294-301.

4. S. Takakuwa. "Design and analysis of computer-aided cart systems for picking discrete items," Proceedings of the 1991 Winter Simulation Conference, B. Nelson, W. Kelton, and G. Clark, eds., 365-374.

5. Tezuka, S. and M. Fushimi. "Fast generation of low discrepancy points based on Fibonacci polynomials," Proceedings of the 1992 Winter Simulation Conference, J. Swain, D. Goldsman, R. Crain, and J. Wilson, eds., 433-437.

6. S. Umeda. "A manufacturing-oriented simulation package to support systems planning and its operation," Proceedings of the 1992 Winter Simulation Conference, J. Swain, D. Goldsman, R. Crain, and J. Wilson, eds., 890-898.

7. Fujihara, M. and K. Yoneda. "Simulation through explicit state description and its application to semiconductor fab operation," Proceedings of the 1992 Winter Simulation Conference, J. Swain, D. Goldsman, R. Crain, and J. Wilson, eds., 899-907.

8. Morito, S.; Lee, K.; Mizoguchi, K.; and H. Awane. "Development of a simulation-based planning system for a flexible manufacturing system," Proceedings of the 1992 Winter Simulation Conference, J. Swain, D. Goldsman, R. Crain, and J. Wilson, eds., 908-915.

9. Ozeki, S. and N. Ikeuchi. "Customer service evaluation in the telephone service provisioning process," Proceedings of the 1992 Winter Simulation Conference, J. Swain, D. Goldsman, R. Crain, and J. Wilson, eds., 1341-1348.

10. Hasegawa, H. and A. Inoue. "Approach to nation-wide network simulation making virtual reality for telecommunication network management," Proceedings of the 1992 Winter Simulation Conference, J. Swain, D. Goldsman, R. Crain, and J. Wilson, eds., 1374-1379.

11. Nakamura, S.; Hashimoto, C.; and O. Mori. "Precise and flexible modeling for semiconductor wafer fabrication," Proceedings of the 1993 Winter Simulation Conference, G. Evans, M. Mollaghasemi, E. Russell, and W. Biles, eds., 804-813.

12. Corbett, C. and E. Yucesan. "Modeling just-in-time production systems: a critical review," Proceedings of the 1993 Winter Simulation Conference, G. Evans, M. Mollaghasemi, E. Russell, and W. Biles, eds., 819-828.

13. Morito, S.; Lee, K.; Mizoguchi, K.; and H. Awane. "Exploration of a minimum tardiness dispatching priority for a flexible manufacturing system - a combined simulation/optimization approach," Proceedings of the 1993 Winter Simulation Conference, G. Evans, M. Mollaghasemi, E. Russell, and W. Biles, eds., 829-836.

14. S. Takakuwa. "Design and cost-effectiveness analysis of large-scale AS/RS-AGV systems," Proceedings of the 1993 Winter Simulation Conference, G. Evans, M. Mollaghasemi, E. Russell, and W. Biles, eds., 851-856.

15. Hasegawa, H. and A. Inoue. "Parallel event processing for circuit-switched telecommunication network simulation," Proceedings of the 1993 Winter Simulation Conference, G. Evans, M. Mollaghasemi, E. Russell, and W. Biles, eds., 1361-1362.

16. U. Shigeki. "Discrete event simulation in Japan -- state-of-the-art and its future," New Directions in Simulation for Manufacturing and Communications, 73-78.

17. Kawada, S.; Kawata, S.; and A. Watanabe. "A manufacturing system modeling using a scene transition net," New Directions in Simulation for Manufacturing and Communications, 86-92.

18. Katayama, H., Goto, S., Tsurumi, D.; Hwang II, H.; and J. Nakane. "Design of work formation for production system involving handicapped workers," New Directions in Simulation for Manufacturing and Communications, 93-99.

19. Takahashi, K.; Nakamura, N.; and K. Ohashi. "A study on JIT production system via discrete event simulation," New Directions in Simulation for Manufacturing and Communications, 105-109.

20. Kobayashi, M.; Tobe, Y.; and Y. Shiobara. "A LAN simulator based on object-oriented discrete event-driven model," New Directions in Simulation for Manufacturing and Communications, 110-114.

21. Hasegawa, H. and A. Inoue. "A parallel simulation of circuit-switched telecommunications networks," New Directions in Simulation for Manufacturing and Communications, 115-120.

22. Tezuka, S. and T. Tokuyama. "Low-discrepancy sequences based on Pascal's triangle," New Directions in Simulation for Manufacturing and Communications, 134-136.

23. Tamaki, H.; Nishikawa, Y.; Mukumoto, S.; and M. Araki. "Simulation-based scheduling using generalized Petri nets," New Directions in Simulation for Manufacturing and Communications, 141-147.

24. Shiizuka, H. and M. Suzuki. "Modeling techniques of AGV networks by Petri nets in flexible manufacturing systems," New Directions in Simulation for Manufacturing and Communications, 154-160.

25. Nakamura, T. and Y. Hibino. "An analysis on pedestrian traffic flow using discrete event simulation," New Directions in Simulation for Manufacturing and Communications, 188-192.

26. H. Sakasegawa. "AEI algorithm to generate normal random variates," New Directions in Simulation for Manufacturing and Communications, 193-196.

27. Morito, S. and K. Lee. "An application of simulated annealing for an FMS dispatching priority problem," New Directions in Simulation for Manufacturing and Communications, 197-203.

28. Zhang, Y.; Kameda, H.; and K. Shimizu. "A simulation study of dynamic load sharing in heterogeneous distributed systems," New Directions in Simulation for Manufacturing and Communications, 229-234.

29. Ashihara, H.; Shimizu, K.; and K. Koyama. "Simulation study on the scalability of adaptive load sharing policies in distributed systems," New Directions in Simulation for Manufacturing and Communications, 241-244.

30. Arai, E.; Uchiyama, N.; and A. Sae-Tang. "New part distribution of CAD/CAM/FA in distributed manufacturing environment," New Directions in Simulation for Manufacturing and Communications, 262-268.

31. Fujii, S.; Hirashima, Y.; Tsunoda, H.; Yamane, M.; and M. Hirano. "A basic study on a distributed simulation for virtual manufacturing," New Directions in Simulation for Manufacturing and Communications, 277-281.

32. Muro, Z and T. Terano. "Rule-based simulation with a classifier system for steel manufacturing processes," New Directions in Simulation for Manufacturing and Communications, 294-300.

33. J. Rajasekera. "Application of simulation in product costing," New Directions in Simulation for Manufacturing and Communications, 315-319.

34. Sakai, T. and H. Ogiwara. "Importance sampling for trellis-coded modulation scheme," New Directions in Simulation for Manufacturing and Communications, 320-325.

35. Koshikawa, K. and K. Tanaka. "Large scale simulation study for paint facilities in an automobile plant," New Directions in Simulation for Manufacturing and Communications, 337-343.

36. Y. Yazaki. "Manufacturing lead-time reduction activity and simulation," in New Directions in Simulation for Manufacturing and Communications, 350-352.

37. Kawahara, R.; Asaka, T.; and S. Sumita. "Simulation analysis of overload control for intelligent network," New Directions in Simulation for Manufacturing and Communications, 373-379.

38. Takeo, A. and H. Masahiro. "Estimation of telecommunication network reliability when simulating disasters," New Directions in Simulation for Manufacturing and Communications, 387-389.

39. Kamimura, S.; Sakamoto, H.; Fujihara, M.; Kano, T.; and K. Yoneda. "An O(log n) job shop simulator for wafer fabs," New Directions in Simulation for Manufacturing and Communications, 413-418.

40. K. Tanaka. "Simulation of line balancing and task assignment for operators in a general assembly facility in an automobile plant," New Directions in Simulation for Manufacturing and Communications, 423-427.

41. Fukuda, Y.; Ikeda, Y.; Mituyuki, K.; and M. Tukada. "Integrated environment for production system design simulations," New Directions in Simulation for Manufacturing and Communications, 434-438.

42. Cheng, Y.; Ikeda, H.; Tomii, N.; and Y. Hayashi. "A feasible partial train traffic simulation using diagram expressed in network," New Directions in Simulation for Manufacturing and Communications, 439-445.

43. H. Takahashi. "A simulation approach to demand forecasting for high-speed railway traffics under a constraint of seat capacity," New Directions in Simulation for Manufacturing and Communications, 446-450.

44. Y. Shibata. "Structural modeling for designing holonic systems," New Directions in Simulation for Manufacturing and Communications, 463-469.

45. Fujimoto, H. and K. Yasuda. "Experimental investigation of decision rule sets for multilevel job shop scheduling using a computer simulation," New Directions in Simulation for Manufacturing and Communications, 475-481.

46. Y. Hirakawa. "A simulation technique for analyzing the performance of flexible manufacturing systems," New Directions in Simulation for Manufacturing and Communications, 489-492.

47. Nakano, M.; Sugiura, N.; Tanaka, M.; and T. Kuno. "ROPSII: manufacturing system simulator with object-oriented simulation language," New Directions in Simulation for Manufacturing and Communications, 493-498.

48. Inoue, I. and M. Fuyuki. "A simulation based planner's tools-system for supporting production scheduling activities," New Directions in Simulation for Manufacturing and Communications, 505-511.

49. Hiraki, S. and H. Katayama. "Designing of an international co-operative global complimentary production ordering system," New Directions in Simulation for Manufacturing and Communications, 519-525.

50. Feigenbaum, E.; Friedland, P.; Johnson, B.; Nii, H.; Schorr, H.; Shrobe, H.; and R. Engelmore. "Knowledge-based systems research and applications in Japan, 1992," AI Magazine, Vol. 15, No. 2, Summer 1994, pp. 29-43.