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Simulation Project Characteristics in Industrial Settings

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In a survey of practitioners of discrete-event simulation from industry and research institutes who "build models for money," we asked about project goals, user backgrounds and training, organizational types and activities, software and hardware choices, modeling team composition, and effort allocation within a modeling project. We found that (1) only about half of the practitioners have three or more years experience, (2) many academics feel strongly affiliated with their industry clients rather than with their university employers, (3) shop-floor supervisors rarely lead simulation projects, even though their knowledge of the system may be unparalleled, (4) simulation models are generally described as unique custom models, yet practitioners indicate that they commonly build similar models, (5) although simulators (parameter-driven simulation environments that require no user coding) are now available, few respondents indicate using any simulators for simulation projects.

Simulation is one of industry's most used operations research techniques [Lane, Mansour, and Harper 1993]. Its uses range from answering questions about work-in-process and production feasibility

to comparing alternative plans for system routing and scheduling. Yet, in spite of (or perhaps because of) its broad user base, opinions about its efficacy as an industrial decision support tool vary greatly. Horror

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stories are as numerous as success stories.

Many authors [Dietz 1992; Law 1986; Pegden et al. 1990; Sadowski 1989; Thesen and Travis 1988; and Ulgen 1991] have written about simulation methodology. Here at the Systems Simulation Laboratory (SSL) at Arizona State University, our studies are leading us to believe that successful simulation practice is more dependent on methodology than on software tools.

As part of a funded research project for the National Institute of Standards and Technology and the Institute for Manufacturing and Automation Research, we developed and administered a questionnaire [Cochran, Manathkar, and Mackulak 1993] to practitioners in a wide range of industrial settings. Surveys on simulation are not unusual. *Industrial Engineering* magazine [Torrey, July 1992, p. 43, and Torrey, May 1993, p. 10] reports the results from fax surveys on simulation and its role in an industrial engineer's job. Unfortunately, these surveys provide only limited insight on how simulation is practiced on the job.

A decade ago, Christy and Watson [1983] published results similar to ours for a sample of nonacademic simulation users. Many of their issues remain pertinent, but they did not collect data on the composition of simulation teams and the effort allocation within them. Furthermore, since their study, computer hardware and simulation software have changed. Our objectives in writing this paper are to inform *Interfaces* readers about current simulation practices in industrial settings, describe how those practices have changed over the past decade, and focus on the skill set of the individual practitioner now at work in

the field.

The Survey Instrument

A copy of our questionnaire is available by mail from the SSL. The questionnaire is four pages long and consists of 27 questions. Questions are multiple choice, and space is provided to allow participants to write in nonstandard responses. From pre-survey studies, we estimate that it takes about 10 minutes to complete the questionnaire. The questions are grouped into the following categories:

- The user's background and training in simulation,
- How the user's employer uses simulation,
- The characteristics of a typical modeling project, and
- How effort is allocated in a simulation project.

We stored and analyzed the results from the survey using the PARADOX database software from Borland International.

Survey Participants and Respondents

We targeted a small group of active simulation practitioners. We did not send the survey to random organizations, individuals, or universities. Rather, we solicited input from simulation practitioners in industry, research institutes, simulation consulting organizations, and United States simulation funding agencies who have "built models for money." We sent the questionnaire electronically and by mail to a sample of SCS (Society for Computer Simulation) members, System Simulation Laboratory industrial and academic contacts, and all subscribers of *Simulation Digest* (an electronic simulation newsletter posted to the USENET news group: comp.simulation.misc).

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We received a total of 138 survey responses from individuals in 11 countries. Of the 400 surveys mailed, 95 were returned for a response rate of around 24 percent. We received an additional 43 responses from readers of the *Simulation Digest* in which we had included the survey. Since people can receive the *Simulation Digest* by many different methods, we cannot compute a response rate for that publication. We did not receive all the responses at the same time. We used a follow-up strategy that allowed us to verify that the initial nonrespondents did not differ statistically from respondents. We, therefore, have a good level of confidence that our results represent the behavior of the target population (subject, obviously, to sampling error).

The survey respondents are a mixture of industrial practitioners, academics, simulation consultants, and others who use simulation in a variety of fields (for example, manufacturing, airlines, postal services, research laboratories, and service companies). The specific responses by job classifications are industry (48 percent), academia (46 percent), and government (six percent). We have analyzed the responses both by individual job classification and by combining all classifications. Except in a few

Years	Percent
3 or more	56%
2 to 3	9%
1 to 2	15%
1 or less	20%

Table 1: Survey respondents indicate that over half have three or more years of simulation experience.

Education	Percent
University classes	58%
Industrial training	23%
Workshops and seminars	11%
None	8%

Table 2: The primary source of simulation training was university instruction.

cases, there are no significant differences among the results. To simplify our presentation, we will present combined results and will highlight any differences that a separate analysis by job classification provides. Let us turn our attention now to the survey results.

Only about half of the practitioners have three or more years of experience (Table 1). When asked about their primary method of obtaining training in simulation (Table 2), 58 percent learned at a university, while the next largest percentage (23 percent) learned in an industrial seminar. Eight percent indicate that they have no formal education in simulation!

The practitioners exhibit a wide range of past experience (Table 3). Twenty-five percent have participated in more than 15 projects, while more than a third have participated in fewer than five.

Number of Projects	Percent
Less than 5	36%
Between 5 and 10	28%
Between 10 and 15	11%
More than 15	25%

Table 3: The respondent group includes practitioners who have participated in over 15 projects (25 percent) as well as those who have been involved in under five projects (36 percent).

Primary Business Activity	Percent
Education and Research	33%
Project	17%
Mass production line	14%
Batch production	9%
Job shop	7%
Continuous flow line	5%
Other	15%

Table 4: The primary business activities of the respondents' organizations cover a range of application areas.

Organizational Use of Simulation

We asked the practitioners to identify their primary business activity (Table 4). The seven business activity categories in our survey are education and research (teaching, writing publications, for example, university), project (custom-made products, quantity of one, for example, shipbuilding, space vehicles), mass production line (high volume, discrete production, similar products, for example, automobiles, toys), batch production (medium volume, periodic batches, for example, chemicals, industrial equipment), job shop (low volume, small batches of products, for example, machine tool shops, commercial printing), continuous flow line (high volume, continuous production, for example, oil re-

fineries, grain mills), and other.

Although almost half of the responses we received came from academics, only 33 percent of the participants reported their primary business activity to be education and research. It seems that many academics who "build models for money" feel strongly affiliated with their industrial clients rather than with their university employers.

The other production activities reported are diverse and include project-oriented activities (17 percent), mass production lines (14 percent), batch production (nine percent), and continuous flow line (five percent). A combined 15 percent (no one tallying more than two percent) are in areas other than those we specified, of which the largest two are software development and transportation modeling. Simulation is indeed widely used.

Within differing business activities, common goals for a simulation project are evident (Table 5). The most common goal is design (facility design, system development and design). Next is research (product development, industry modeling), followed by scheduling (shop floor work-flow analysis, priorities, and due dates). A moderate use of simulation is reported for

Simulation Project Goal	3 Years or More	2 to 3 Years	1 to 2 Years	1 Year or Less
Design	23%	23%	22%	21%
Research	23%	17%	20%	26%
Scheduling	19%	23%	21%	14%
Planning	16%	17%	15%	18%
Assignments and allocation	15%	17%	22%	12%
Other	4%	3%	0%	9%

Table 5: A breakout of simulation project goals compared to years of practitioner simulation experience shows no significant variation.

planning (forecasting, analysis of marketing strategies, consumer behavior prediction) and also for assignment and allocation problems (personnel analysis, resource allocation, personnel scheduling). Other uses of simulation reported include testing scientific theory, studying health care systems, modeling weapon systems, and analyzing data. A separate analysis by job classification reveals that industry's top goals are slightly different—design and planning. In a separate study [Ozdemirel, Mackulak, and Cochran 1993], we review published simulation modeling papers and gave a detailed breakdown of simulation project goals.

The level of experience among practitioners tackling a given goal is also shown in Table 5. Experience levels are not uniformly distributed over simulation project goals; however, the differences are not statistically significant. That is, people of equal skill are addressing each of these goals in industry.

Although companies are thought to readily hire people with simulation skills on a consultant basis, about 30 percent of the practitioners surveyed indicated (Table 6) that they know of no obstacles to per-

Obstacle	Percent
No obstacles	30%
Lack technical background	21%
Need for dedicated personnel	15%
Training	12%
Cost	10%
Other	12%

Table 6: There are not always obstacles to performing simulation in-house. When obstacles exist, they are primarily related to a shortage of experienced personnel.

Job Function	Percent
Systems analyst	28%
Simulation developer (in-house)	24%
Consultant (external)	13%
Shop-floor supervisor	12%
Manager	12%
Other	11%

Table 7: The leader of a simulation team is typically a systems analyst or developer, despite the fact that the shop-floor supervisor may know the system best.

forming simulation in-house. Obstacles to in-house simulation analysis identified include lack of technical background (21 percent), need for dedicated personnel (15 percent), training (12 percent), and cost (10 percent). Additional obstacles include lack of management support and inadequate time for development.

Identifying the best leader for a simulation team is not a well-understood decision. Currently the majority of team leaders are simulation specialists and systems analysts (Table 7).

Characteristics of a Typical Modeling Project

The frequency of use of simulation within an organization varies widely. Many respondents (39 percent) build simulation models weekly (Figure 1), while some (18 percent) use simulation on a yearly basis. Simulation models are generally described as being unique, custom modeling tasks, but practitioners indicate that they commonly build similar models. At the SSL, we have pursued the intriguing idea of finding generic models and systematically using them as the basis for model construction [Mackulak and Cochran 1990; Lung et al. 1994].

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Figure 1: Frequency of industry use of simulation varies widely, but similar problems are commonly modeled.

Because analysts often develop similar models, we asked participants how they view reusing parts or even entire models. Five percent describe this task as very easy, 24 percent conclude it is easy, 27 percent say it is difficult, and two percent say it is very difficult. Around 33 percent were neutral on this question, but only nine percent indicated that they never reuse models.

Typically it takes one to three months to complete a simulation project (Table 8). The majority reported that the average person-effort required to complete a project is over one week but less than three months.

A simulation project can be described in

	1 Week or Less	1 Week to 1 Month	1 to 3 Months	3 to 6 Months	More than 6 Months
Minimum time for a project	49%	25%	13%	6%	7%
Average time for a project	4%	20%	31%	16%	29%
Maximum time for a project	0%	4%	15%	16%	65%
Person-effort to complete a project	6%	36%	29%	13%	16%

Table 8: Simulation projects take less than a week at a minimum, to more than six months at a maximum. Most projects take between one week and three months average person-effort.

terms of the language used to develop the model (Table 9). The use of a general programming language for model development continues. In fact, only 18 percent of the respondents do not use a general purpose programming language. Although Christy and Watson do not report the use of C in their 1983 survey, it is now equal to FORTRAN in its use. Academics sometimes use PASCAL, but there is little industry interest present for PASCAL in our sample.

In addition, most practitioners also use a general purpose simulation language because general simulation languages offer many advantages. Of the general purpose simulation languages, SLAM and SIMAN are the most popular among our survey target audience in the production and service industries. Industry participants reported a higher use of SIMAN, and academic participants reported a higher use of SLAM.

Although simulators (parameter-driven simulation environments that require no user coding) have been developed and released in recent years, only 40 percent of respondents indicated using any simulators for simulation projects. The most popular is ProModel. Because it relates to our work at the SSL, we asked if participants had used an intelligent simulation environment

General Purpose Languages		General Purpose Simulation Languages		Special Purpose Simulators	
C	28%	SLAM II	28%	PROMODEL	14%
FORTRAN	27%	SIMAN	28%	SIMFACTORY	8%
PASCAL	7%	GPSS	11%	FACTOR	4%
BASIC	6%	SIMSCRIPT	6%	WITNESS	2%
LISP	4%	Other	11%	Other	12%
Other	10%	None	16%	None	60%
None	18%				

Table 9: When performing a simulation study, most respondents use a specific language. The distribution of languages and environments are categorized above by language type.

(a simulator that helps users to apply simulation methodology using artificial intelligence techniques). Since such environments are only now coming to market, it was not surprising that 80 percent responded "no."

With the arrival of faster microcomputers, the speed disadvantage of running a simulation model on a personal computer is continually diminishing. Thus, it is not surprising that most respondents now run simulation packages primarily on personal computers and workstations (Table 10). In analyzing the responses by job classification, we found that industry's use of mainframes is small compared to that of universities. Few industry modeling projects use mainframes. This could help explain the higher use of SLAM by universities and of SIMAN in industry. SIMAN was originally

Computer Hardware	Percent
Personal computer	42%
Workstation	29%
Mainframe	20%
Mini-computer	9%

Table 10: The computer hardware used for simulation projects is now dominated by personal computers and workstations.

designed and released on personal computers while SLAM was adapted to personal computers at a later date. Current budget problems at universities may be restricting access to personal computers. Universities may therefore have stayed with their original mainframe product (SLAM) while industry may have selected a product designed for personal computers (SIMAN).

Although respondents indicate that the use of OS/2 is increasing, DOS (and Windows) for personal computers and UNIX (used on workstations) remain the most preferred operating systems (Table 11).

Operating System	Percent
DOS	29%
UNIX	27%
OS/2	13%
VAX	13%
Macintosh	7%
CMS	5%
MVS	3%
Other	3%

Table 11: The responses concerning the computer operating systems used for simulation projects closely follow the responses pertaining to hardware preferences.

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These preferences correspond to our findings that personal computers and workstations are the top hardware platforms.

Allocation of Effort in a Simulation Project

To estimate how effort is allocated in simulation projects, we used the 10 phases of a simulation study defined in Pritsker [1986, p. 10]. We asked respondents to rank each phase on a scale of one to five, where one is the easiest and five is the most difficult (Table 12). They indicate that problem formulation is the most difficult simulation phase (3.73 out of five), closely followed by data acquisition (3.56), validation (3.44), and model building (3.30).

We also asked our practitioners to divide total project effort among the simulation phases. Respondents estimate that data acquisition is the most time-consuming activity, requiring almost 15 percent of total project effort. The next most time-consuming phases are problem formulation, model translation, and model build-

ing.

For each phase of the simulation process, we asked practitioners to estimate the percentage of that phase that is computer-assisted. They reported that the most computer-intensive tasks are experimentation, model translation, and verification. Software developers should note that although problem formulation uses 13.80 percent of the project's effort and was rated the most difficult phase, it receives only about nine percent of assistance from the computer. This is clearly an area in which development work must occur.

Conclusions

Sadowski [1989] says that "the art of modeling is best learned through experience." In our survey of simulation practitioners and researchers who "build models for money," we sought to tap their combined experience to assess current simulation practices, observe changes, and identify trends for the future.

Advances in computer hardware and

Phase of a Simulation Project	Difficulty (1 to 5)	Time	Computer-Assist
Problem formulation	3.73	13.80%	9.07%
Model building	3.30	10.94%	23.98%
Data acquisition	3.56	14.75%	36.93%
Model translation	2.37	13.87%	62.66%
Verification	2.74	8.15%	61.80%
Validation	3.44	8.18%	47.35%
Strategic and tactical planning	2.91	6.61%	26.92%
Experimentation	1.84	7.55%	83.11%
Analysis of results	2.98	9.04%	45.00%
Implementation and documentation	2.59	7.11%	42.51%

Table 12: In estimating effort allocation in a typical simulation project, respondents rated the difficulty of each phase on a scale of one to five, where one is easiest and five is most difficult. They also estimated the percentage of effort (time) each phase consumes of the total project effort (the percentages in this column total 100 percent). In the Computer-Assist column, they estimated the current percentage of computer assistance in each phase of a simulation project.

software caused the most changes in the past decade:

- (1) The C programming language has achieved the same level of use as FORTRAN.
- (2) The use of general purpose programming languages for simulation is decreasing.
- (3) SIMAN and SLAM are currently the most used simulation languages.
- (4) Industry uses mostly PCs rather than mainframe computers.
- (5) The use of simulators (ProModel, Witness, and so forth) is slowly increasing.

What does the future hold? Christy and Watson [1983], perhaps wisely, did not venture an opinion in these pages 10 years ago, but we have a few ideas. Simulation languages may experience a fate similar to general programming languages, with simulators taking their place. Banks, Aviles, McLaughlin, and Yuan [1991] agree that while the current generation of simulators has disadvantages, these limitations will shrink in future software releases. Mainframes and FORTRAN may finally disappear. Opportunities for consulting may die out as simulation tools incorporate proper methodology. Libraries of preprogrammed simulation models or reusable modules may become available. In a software market saturated with products, new product development must focus more on the practitioner's needs, such as built-in training. Finally, we hope that the results of our survey aid decision makers in planning, staffing, and managing simulation projects.

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