Selection of a Simulation Language for an MBA Modeling and Simulation Course

By

NORMAN P. ARCHER
Associate Professor of Management Science
Faculty of Business

FACULTY OF BUSINESS

McMASTER UNIVERSITY

HAMILTON, ONTARIO

Research and Working Paper Series No. 225
June, 1984

SELECTION OF A SIMULATION LANGUAGE FOR AN MBA MODELING AND SIMULATION COURSE

Norman P. Archer
McMaster University

ABSTRACT

A study was carried out with two student sections of an MBA modeling and simulation course, to examine the feasibility of switching to a different simulation language from the one currently used. Data collected during the study also indicated the value of a project-oriented approach in the course, and indicated that more emphasis could be placed on learning the simulation language by self-teaching, leaving more class time for learning other aspects of simulation.

Subject Areas: Education, Systems, and Simulation.

INTRODUCTION

Simulation has become a widely recognized technique for studying the behavior of complex business and industrial systems. For this reason, modeling and simulation have become regular topics in both undergraduate and graduate business programs. The Curriculum Committee on Information Systems of the Association for Computing Machinery (ACM) has included modeling and simulation in its recommended program [14] although these topics represent only about half of one of the recommended courses (IS7-Modeling And Decision Systems) for a graduate MBA program in information systems. The ACM recommendations also suit the general requirements of the AACSB (American Assembly of Collegiate Schools of Business).

While it is important to develop minimum standards for material taught in business system simulation courses, the advance of technology and the development of newer simulation packages with improved features require a constant effort to upgrade and advance the material taught in these courses.

In the McMaster University MBA program, the Modeling and Simulation course Q715 is a regularly scheduled course available for students enrolled in any of the three classifications (full time, part time and co-op) in the MBA program. This course is normally taken by most of the students electing the Information Systems, Operations Management, or Management Science academic streams, and occasionally by students in other streams such as Finance, Marketing and Accounting. The enrolment in this course fluctuates between 20 and 40 students each year, and it is offered in both evening and day sections.

The writer has taught the modeling and simulation course for a number of years, using GPSS as the simulation language. Recently, due to the expressed interest of students taking the course and due to the ongoing evolution of a wide variety of general purpose simulation languages, a study was undertaken to reorganize the course, with major attention being given to the possibility of replacing GPSS with a more versatile language. This paper reports on the results of that study.

THE STUDY

Modeling and Simulation (Q715) is a second year MBA one semester course. Prerequisites include a beginning course in statistics and an introductory course in computer programming (BASIC or FORTRAN) and management science or its equivalent. The mark weight is 30% each on midterm and final exams, 30% on the project, and 10% on assignments. The general course outline is given in Table I.

Table I

Modeling And Simulation Course Outline

Topic	Duration (weeks)
1. Introduction to modeling and simulation	2
2. Introduction to the simulation language used in the course	4
3. General procedures for planning and carrying out a simulation project	1
4. Statistical considerations	3.5
5. Survey of other simulation languages	1
6. Class presentations of projects	1.5
Total	13

Students are required to form groups of from one to three persons to undertake real simulation projects. The project customer can be either off or on campus. Typical projects undertaken during the past few years have included a simulation of earth moving at a major construction project, scheduling transcription work at a hospital, bus scheduling, planning for airport expansion, cafeteria operations, etc. A total of over 150 projects of this type have been undertaken.

Planning and development work on the class projects are monitored carefully, especially during the early phases. Student groups must prepare their proposals early in the term for approval, and care is taken to prevent students from taking on projects which are too ambitious. Near the end of the term, each student group makes a class presentation of its project. The purpose of this presentation is two-fold: to permit students to gain from the experience of others, and to allow students to benefit from constructive criticism from the instructor and other students.

As mentioned previously, one of the main objectives of this study was to determine if a simulation language other than GPSS would be suitable for the course. There is a wide variety of simulation software available to satisfy just about every practical need, with more constantly being made available. For example, articles by unknown authors in Simulation [22] [23] list the characteristics of some 48 simulation packages available for a variety of machines. A large number of these packages will also run on various types of microcomputers, thus keeping simulation methodology abreast with the evolution of computer systems. However, these listings are by no means exhaustive and not all of these packages are sufficiently general or otherwise suitable for business students.

The general preference for particular simulation languages has a direct impact on the material to be found in the introductory texts available in the field. A sampling of some of the more recent general texts on simulation, along with the languages discussed in reasonable detail in these texts, appear in the table below.

Table II

Language Discussions In Contemporary Simulation Texts

TEXT	FORT	GPSS	SMSCPT	SLAM	SIMULA	CSMP	DYNMO
Fishman [4]		X	X		X		
Gordon [7]		X	X			X	X
Maryanski [13]		X	X			X	X
Law and Kelton [12]	X	X	X	X			
Banks and Carson [2]	X	X	X	X			

FORTRAN is included as a simulation language in two of these texts, although it is unlikely that business students would be taught simulation with FORTRAN, given all the power available in the general purpose simulation languages. Law and Kelton, and Banks and Carson also give summaries and comparisons of several of the languages mentioned, respectively. These authors also tend to focus on GASP IV as well as SLAM, but since GASP IV is a precursor of SLAM, their evaluation of GASP IV can also be helpful when considering SLAM.

From the point of view of the beginning user, the graphical modeling language available with GPSS, the network models of SLAM, and the flow models of DYNAMO [5] are helpful in planning simulation solutions. Unfortunately there are no standards for modeling languages such as these, as there are no standards for simulation languages. However, for planning a simulation solution, there is nothing to prevent the user from using a flowchart to lay out a simulation model in any language.

Table II above includes some of the more popular general purpose simulation languages in use in North America. SIMULA was considered in this study since it is fairly widely used in Europe, although it is not currently popular in North America.

Since one of the main objectives of the search was to find a language that was flexible enough to handle both discrete and continuous simulations, the continuous simulation languages CSMP and DYNAMO were ruled out. Of the three remaining alternatives, SIMULA and SLAM can handle both discrete and continuous problems, and although SIMSCRIPT is a discrete simulation language, Delfosse [3] has developed a version which can handle both discrete and continuous simulations. After a cursory consideration, SIMULA was ruled out because of its cost and its lack of wide acceptance in North America, and SIMSCRIPT was ruled out because of its cost. SLAM was selected for further investigation because of its flexibility and its low cost, and also because there are indications that it is beginning to become a popular pedagogical language, as indicated by its mention in several more recent general texts on simulation [2] [12].

Other workers have compared the relative merits of GPSS and other simulation languages. For example, LaPara and Whitehouse [11] compared GPSS with Q-GERT (one of the ancestors of SLAM) and found on balance that GPSS had more desirable characteristics than Q-GERT. Fortunately, most of the defects in Q-GERT mentioned in this paper appear to have been remedied in the SLAM implementation.

By way of background on SLAM (the candidate language), and GPSS (the currently used language), some history on the development and origins of each language is useful in understanding their properties and capabilities.

GPSS (General Purpose Simulation System) was developed at IBM by Geoffrey Gordon, beginning in 1960 [8]. The technique of block diagram models for discrete simulation which is familiar to the GPSS user is roughly equivalent to flowcharting. In GPSS, each program statement has associated with it a special symbol which can be used to map out the model before it is necessary to convert it to a program. This approach is useful in the initial planning of a simulation program. GPSS has available more than 50 different block types, a daunting prospect for the beginner, although many of these block types are rarely used in a beginning course. But, as in any other programming language, internal program documentation is better in the long run than block or flow diagrams for documenting the operations of the program.

GPSS V, the most widely used version of GPSS, has been adapted by a number of vendors (most versions are written in assembly language) to run on a variety of machines, including most mainframe and supermini systems of IBM and other vendors. A more recent version, GPSS/H [9] is available for IBM systems, and is claimed to execute faster than GPSS V. Two excellent introductory texts for GPSS V are by Gordon [6] and Schriber [20].

SLAM (Simulation Language for Alternative Modeling) is a descendant of two other simulation languages, GASP and Q-GERT. GASP was originally developed by Kiviat [10] for discrete simulation. It evolved into GASP IV which is a combined discrete and continuous language in which the user writes FORTRAN subroutines to accomplish the simulation within the GASP IV framework. The GASP approach to modeling is very flexible, but it is tedious to model standard activities and events in this manner, and it requires a good knowledge of FORTRAN. The Q-GERT simulation language is a process-oriented language which uses standard statements to handle a set of network-oriented processes. Q-GERT and GASP IV were both developed by Alan Pritsker [16] [15]. SLAM is the refined combination of Q-GERT and GASP IV, with suitable additional capabilities to allow full interaction among the different modes (network, discrete event and continuous). This gives the user full flexibility in SLAM to handle many of the standard processes encountered in discrete simulation problems. For many discrete models, there is no need to go beyond the network mode in order to solve problems satisfactorily (see Appendix II for an example). The network mode is roughly equivalent in programming power to GPSS. The network symbols associated with this mode are often helpful in planning simulation programs, as are the block symbols in GPSS.

SLAM was developed by A. Pritsker and C. D. Pegden, and introduced in 1979. The developers also authored the primary reference for SLAM [17]. The current version of the software package, SLAM II, is available from Pritsker and Associates, and will run on a variety of machines, including the IBM personal microcomputer. Little adaptation is required among machines because the package is written in Fortran 77.

In order to compare SLAM and GPSS in compatible environments, the languages were each used for one section of the modeling and simulation course. The course outline, examinations, assignments and project approach were the same in each case, with the only difference being in the language used by the students in each section. The day section of 14 students used GPSS and the evening section of 9 students used SLAM. To a certain extent bias could arise in student attitude towards the language, because the majority of the evening students were part-time, and most part-time students taking this course tend to have engineering backgrounds, while the full-time students tend to be more balanced between engineering and other backgrounds.

To monitor the perceptions and performance of students taking the course, a questionnaire was administered at the beginning of the course, followed one week later by an identical questionnaire to measure instrument reliability. A third questionnaire was administered at the end of the course to measure attitude changes or preferences in the two groups of students.

RESULTS OF THE STUDY

Section A of the appendix lists four questions which appeared on each of the questionnaires, followed by a statistical analysis of the responses to the questions. In terms of change in student attitudes during the course, the day students showed a significant attitude change towards feeling that modeling and simulation could be more useful in business and industry than they originally thought, but they also felt that modeling and simulation in their future careers would be less useful than they originally expected. Responses by the evening students indicated a perception that modeling and simulation could be used in a wider variety of problems than they expected at the beginning of the course.

Section B of the appendix lists the results of an analysis of some of the other questions asked on the final questionnaire. In question 5, students ranked the most likely application areas of modeling and simulation in their future careers. The top ranked application is "project planning and control systems", which should be taken to mean "the use of modeling and simulation in planning and controlling systems" rather than what might be the more obvious meaning of such applications as PERT techniques, since the latter is an application which was mentioned only in the evening class.

In question 6, students indicated that a combined discrete/continuous application of simulation would likely be most useful to them in their future careers, and in question 7 students indicated that their interests in modeling and simulation had increased as a result of taking the course. Although this indicates a positive attitude towards the course, this finding is not corroborated by the finding in question 1 of section A of the appendix, which indicated there was no significant change in student interests during the course.

Question 8 asked students to rank the factors in the course which contributed to their learning about modeling and simulation. This question contributed a great deal to an understanding of the learning process in the course. Considering all the students, three of the four top-ranked learning activities were project-related, and doing assignments was the second-ranked learning activity. Attending lectures ranked fifth overall, but tied for second rank for the evening students. This difference may be related to the fact that the GPSS text used for the day class [6] is an excellent beginning text and requires very little extra explanation in lectures. The text used for the evening class [17] is more condensed as well as being advanced and difficult to follow for beginners. Hence lectures are needed to bring out important aspects of SLAM as well as to clarify points not mentioned in the text. However, a great deal of additional material not directly related to the simulation language is also used in the course, and this is covered in lectures as well as being made available as background material on library reserve. The SLAM II text is a good reference on this material, but the

GPSS text used in the course contains only information on the GPSS language.

Question 9 was answered only by the evening students (SLAM users) and indicated that only a rudimentary knowledge of FORTRAN would be required for most of the applications of interest to the students. This is not sufficient, of course, for users wishing to use the continuous modeling capability or the advanced discrete capabilities of SLAM, but only two student groups out of the eight evening class groups chose to carry out continuous modeling projects, and only two other groups used any of the advanced discrete functions in the form of FORTRAN subroutines.

The response to question 10 is not surprising, where day students ranked GPSS as their top choice and evening students ranked SLAM as their top choice for the simulation language to be taught in the course, since they would normally choose the language with which they were familiar. However, a lecture was given to each class on the comparative capabilities of the simulation language being used by the other class.

As expected, in question 11 the day students ranked the Gordon GPSS textbook higher in terms of usefulness than the evening students ranked the Pritsker and Pegden SLAM text, since the latter text is more advanced and is rather terse in its discussion of the network simulation capability of SLAM. This capability happens to be very important for teaching introductory discrete modeling and simulation.

Appendix II includes a sample simulation problem and its solution in both GPSS V and SLAM. The most notable difference between the two solutions is the need in GPSS to include the piecewise continuous functions to approximate the random variable distribution functions. Unfortunately, this is necessary even for theoretically known distribution functions such as the negative exponential and the normal distributions shown here. Archer [1] has discussed the problem of fitting empirical distributions to piecewise continuous functions, so this need not create a problem with empirical data. In fact, this overcomes the necessity of having to make assumptions about the underlying probability distribution.

Some of the major faults that may be found with the GPSS language are its lack of flexibility in satisfying unusual user requirements, and its restriction to the use of an integer time clock. To solve the flexibility problem, various techniques have been used, including the standard HELP blocks, and the development of similar packages in more flexible form such as GPSS-FORTRAN by Schmidt [19]. The use of an integer clock requires careful scaling of time in each simulation problem solved. However, the major drawback to GPSS in this course is that it cannot handle continuous or combined continuous-discrete simulation problems.

To compare the resource implications of SLAM and GPSS, six simple class assignment problems were coded in both languages (network mode in SLAM) and the execution times were compared. The average number of statements, including the piecewise continuous function statements in GPSS, were quite comparable, being 26 and 27 respectively for GPSS and SLAM. If the GPSS function statements are not included, then the average instruction count for the GPSS programs drops to 22. For CPU execution time, GPSS is clearly superior. Running GPSS V/6000 on a CDC Cyber 730 computer, the average CPU time for the GPSS programs was 3.6 seconds, and for the SLAM II package on the same computer the average was 12.5 seconds. This is probably due to the fact that SLAM in the network mode basically functions as an interpreter written in FORTRAN. No attempt was made to code the SLAM programs in discrete (equivalent to GASP IV) mode, but this mode could be expected to execute considerably faster. GPSS, although it is also interpretive, is written in assembly language. A factor which may have added to the number of program statements and its slower execution speed is our own inexperience with SLAM. On balance, however, although Gordon [8] has expressed concern about the execution speed of GPSS, it is still far faster than SLAM in network mode, by a factor of about 3. Presumably GPSS/H [9] is even faster yet.

DISCUSSION

Table III is a comparison of some of the characteristics of GPSS and SLAM. Some of the comparison criteria were paraphrased from Shannon [21], but more criteria were added which seemed relevant pedagogically. SLAM has a clear advantage over GPSS in its flexibility for handling either discrete, continuous, or combined simulations. Its process-oriented network option is very closely equivalent to GPSS, as can be seen in the problem solved in Appendix II. On balance, the flexibility of the SLAM language makes it attractive for an MBA course where students need to be given a wide degree of freedom in selecting project topics. In this first use of SLAM in the course, three student groups selected projects which would have been virtually impossible to carry out with a standard discrete simulation language. Two of these projects involved strictly continuous processes, and one was a study of a project scheduling problem.

The data gathered on student attitudes did not indicate any decided differences in attitude toward modeling and simulation between the two student sections as a result of taking the course. The decision on the language to use in the course can thus be based on other factors such as language flexibility which are not necessarily important to the first-time user of a simulation language. The general conclusion is that SLAM is a suitable simulation language for the course, both pedagogically and from the perceptions of the students taking the course. The lack of a suitable introductory language text for SLAM must be dealt with by the development of a set of class notes.

Another very useful result gleaned from this study is that students regard project undertakings as very important in learning the course material. The importance of projects in teaching has been recognized by others [18] [24] [25]. In particular, Zahedi [25] has pointed out the importance of projects in Management Science/Operations Research courses in teaching students the difficulties faced in handling real problems. To accomplish this, students must be involved in real problems as part of their MS/OR training. This may take place in a variety of ways, including project work in their courses.

A final observation from the data is that students can and do learn the simulation language on their own, and they value assignments in learning course material. Thus, there is less need to cover the points made in the text on the simulation language, and more emphasis can be placed on teaching useful hints and taking up assignment solutions in class. This in turn will free up more time for teaching the statistical aspects of simulation, including the gathering and analysis of data, planning experiments, analyzing and interpreting simulation output, and variance reduction. Time must also be taken to discuss simple analytical models both for analyzing simple real problems and for checking simulation models. There is a substantial body of good reference material in all of these important areas of interest for modeling and simulation, much of which is covered in the texts referenced in Table II.

Table III

Comparison Of GPSS And SLAM

Criterion	GPSS	SLAM
Event-scheduling approach	No	Yes (Discrete)
Process interaction approach	Yes	Yes (Network)
Combined discrete-continuous	No	Yes
Natural framework (modeling language) for simulation modeling	Yes	Yes (Network)
Language flexibility	Fair	Excellent
Handle arbitrary random variable distributions	Excellent	Excellent
Mechanism for generating theoretical random variables easily	No	Excellent
Built-in statistics gathering functions	Very good	Good
Ease of producing standard reports	Very good	Excellent
Ease of producing special reports	Fair	Good

Comparison Of GPSS And SLAM(continued)

Criterion		GPSS	SLAM
Output data analysis package		No	No
Ease of learning language		Excellent	Very good
Knowledge/experience to carry out straightforward simulation projects		Moderate	Moderate
Programming effort required		Moderate	Moderate
Application examples in literature		Very good	Good
Texts and manuals incorporating the language		Excellent	Fair
Ease of debugging (diagnostics, trace routines, etc.)		Good	Fair
Degree to which coding is self-documenting		Very good	Very good (Network)
Widespread availability and use of language in industry		Excellent	Good
Language availability on new computers		Fair	Excellent
Portability of language		Fair	Excellent
Availability for different computers		Very good	Excellent
Computer time efficiency	(GPSSV)	Good	Fair (Network)
	(GPSS/H)	Excellent	
Relative software package cost		Moderate	Low
Quality and speed of maintenance support		Good	Very good

ACKNOWLEDGEMENTS

Most of the examples used in this study were coded by Mr. Robert Dalgleish. This project was supported in part by a Hooker Fund Teaching and Learning grant from McMaster University, and partly by the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

[1] Archer, N.P., The Generation Of Piecewise Linear Approximations Of Probability Distribution Functions, Journal Of Statistical Computation And Simulation, 11, 1980, 21-40.

[2] Banks, Jerry, and John S. Carson, II, Discrete Event System Simulation. Englewood Cliffs, N.J.: Prentice-Hall, 1984.

[3] Delfosse, C.M., Continuous Simulation And Combined Simulation in SIMSCRIPT II.5. Arlington, VA: CACI Inc., 1976.

[4] Fishman, George S., Principles Of Discrete Event Simulation. New York: Wiley, 1978.

[5] Forrester, Jay W., Industrial Dynamics. New York: Wiley, 1961.

[6] Gordon, Geoffrey, The Application Of GPSS V To Discrete System Simulation. Englewood Cliffs, N.J.: Prentice-Hall, 1975.

[7] Gordon, Geoffrey, System Simulation (Second Edition). Englewood Cliffs, N.J.: Prentice-Hall, 1978.

[8] Gordon, Geoffrey, The Development Of The General Purpose Simulation System (GPSS). In Richard L. Wexelblat, (Ed.), History Of Programming Languages. New York: Academic Press, 1981, 403-437.

[9] Henriksen, J.O., The GPSS/H User's Manual. Falls Church, VA: Wolverine Software, 1979.

[10] Kiviat, Philip J., Keynote Address: 1981 Summer Computer Simulation Conference. Simulation, January 1982, 29-31.

[11] LaPara, Cynthia Z. and Gary E. Whitehouse, Q-GERT and GPSS: A User's Comparison. In William G. Vogt and Marlin H. Mickle (Ed.) Modeling and Simulation. Proceedings Of The Ninth Annual Pittsburgh Conference. Pittsburgh: Instrument Society of America, 1978, 829-835.

[12] Law, Averill M., and W. David Kelton, Simulation Modeling And Analysis. New York: McGraw-Hill, 1982.

[13] Maryanski, Fred J., Digital Computer Simulation. Rochelle Park, N.J.: Hayden Book Co., 1980.

[14] Nunamaker, Jay F., J. Daniel Couger and Gordon B. Davis, Information Systems Curriculum Recommendations For The 80s: Undergraduate And Graduate Programs. Communications Of The ACM, 25, 1982, 781-805.

[15] Pritsker, A. Alan B., The GASP IV Simulation Language. New York: Wiley, 1974.

[16] Pritsker, A. Alan B., Modeling And Analysis Using Q-GERT Networks. New York: Halsted Press, 1977.

References (continued)

[17] Pritsker, A. Alan B., and Claude Dennis Pegden, Introduction To Simulation And SLAM. New York: Halsted Press, 1979.

[18] Richardson, George P., and David F. Andersen, Teaching For Research In System Dynamics. In Modeling and Simulation (Op. Cit.), 1978, 537-542.

[19] Schmidt, B., Simulation Of Discrete Systems Using GPSS-FORTRAN. The Computer Journal, 25, 84-86.

[20] Schriber, Thomas J. Simulation Using GPSS. New York: Wiley, 1974.

[21] Shannon, Robert E., Systems Simulation. Englewood Cliffs, N.J.: Prentice-Hall, 1975, 105-108.

[22] Unknown, Catalog Of Simulation Software. Simulation, October 1983, 156-160.

[23] Unknown, Additions To The Catalog Of Simulation Software. Simulation, February 1984, 88-91.

[24] Verbrugge, William, A Simulation Course With A Small Computer. In Modeling And Simulation (Op. Cit.), 1978, 533-535.

[25] Zahedi, Fatima, A Survey Of Issues In The MS/OR Field. Interfaces, 14, 1984, 57-68.

APPENDIX I

A. Change In Student Attitudes During The Course

Following are four of the questions which were used in the questionnaires. An analysis of the student responses follows.

1. My interest in modeling and simulation is

    [ ] very substantial

    [ ] substantial

    [ ] moderate

    [ ] little

    [ ] none at all

2. I feel that modeling and simulation in business and industry applications can be

    [ ] very useful

    [ ] useful

    [ ] somewhat useful

    [ ] only occasionally useful

    [ ] not at all useful

3. Computer modeling and simulation

    [ ] can be used on a very limited class of problems

    [ ] can be used on a reasonable variety of problems

    [ ] can be used on a wide variety of problems

4. I feel that modeling and simulation as an applied tool in my future career will be

    [ ] very useful

    [ ] useful

    [ ] somewhat useful

    [ ] only occasionally useful

    [ ] not at all useful

Analysis Of Results

The reliability coefficients shown in the following table are Spearman rank correlation coefficients r_s used to compare the test-retest results for the preceding four questions. The Wilcoxon matched pairs signed ranks test was used to measure significance of attitude change between the beginning and end of the course.

Question	Reliability r_s	Significance of Change During Course	
		Day	Eve
1.	.84	N	N
2.	.57	(.Ø4)[a]	N
3.	.6Ø	N	(.11)[b]
4.	.79	(.Ø8)[c]	N

Note:
(X) implies significance level
N indicates not significant

For those questions in which the change in student opinion during the course appeared to be significant, the direction of change is as follows:

[a] towards more useful

[b] towards a wider variety of problems

[c] towards less useful

B. Student Perceptions After Completing The Course

Responses by students to questions on the final questionnaire were summarized by using sum of ranks or majority voting methods. Note that Day and Evening student response is shown separately only when there was a difference in the responses by these two classes.

5. Application areas for modeling and simulation in my future career would probably include the following (rank in order of importance, starting with 1 as the most important, 2 as the second most important, etc.).

Rank

3 Systems of office functions and activities

2 Systems such as traffic, assembly lines, computers, etc.

4 Flow systems such as chemical plants, refineries, etc.

5 Macro-models of the economy, input-output systems, large scale urban systems, etc.

1 Project planning and control systems

6. Rank the class of simulation below in the order of usefulness to you in your future career, if you were to use simulation in business/engineering applications. Assume that you would have full knowledge of whichever language you required. Rank the most useful as 1, the second most useful as 2, and the third most useful as 3.

Rank

3 Discrete (e.g. GPSS or discrete/network SLAM models)

2 Continuous (e.g. SLAM or DYNAMO models)

1 Combined discrete/continuous/network (e.g. SLAM model)

7. As a result of taking Q715, my interest in modeling and simulation has

Rank

1 Increased

2 Stayed about the same

3 Decreased

Note: No students selected "Decreased".

(continued)

8. Rank in order those factors through which your learning about modeling and simulation was most enhanced in Q715, ranking the most important factor as 1, the second most important factor as 2, and continuing on down to the least most important factor.

Rank All	Rank Day	Rank Eve	
1	1	1	Planning the project
3	3	5	Gathering and analyzing project data
4	4	4	Writing and debugging the simulation program
7	7	7.5	Preparing for and presenting the results of the project verbally
6	6	6	Writing the project report
5	5	2.5	Attending lectures
2	2	2.5	Doing assignments
8	8	7.5	Studying for examinations

9. Please answer this question only if you used SLAM in Q715. I think that to use SLAM in most situations of interest to me would require

Rank Eve Only	
2	A detailed understanding of Fortran
1	Only a rudimentary understanding of the Fortran language
3	No understanding of Fortran at all

10. Based on an objective evaluation of information presented in class on the simulation languages GPSS and SLAM, I think the following would be the best language to use in Q715:

Rank All	Rank Day	Rank Eve	
2	1	3	GPSS
1	2	1	SLAM
3	3	2	Combination as used this year (GPSS in day class and SLAM in evening class). Note that this allows a limited choice for full-time and co-op students and no choice for part-time students.

(continued)

11. The textbook used in this course was

Rank Day	Eve	
1	3	very useful
2	1	useful
3	2	somewhat useful
4.5	4.5	only occasionally useful
4.5	4.5	not at all useful

Note: No students checked either of the last two categories. Because the Day and Evening students used different texts, the "All" column is not relevant to this question.

APPENDIX II

Sample Simulation Problem

Problem Statement.

People arrive to use a single telephone at the average rate of one every 10 minutes. The time between arrivals is an exponentially distributed random variable. A call takes a random amount of time which is normally distributed with a mean of nine minutes and a standard deviation of two minutes.

If the telephone is busy at the time of arrival of a customer, half the customers decide to wait, while the other half go away for five munutes and then come back to wait until they do make their calls. People who decide to wait in the first place go ahead of anyone who left. Simulate the completion of 100 calls.

(over)

GPSS Solution

```
*    SAMPLE TELEPHONE BOOTH PROBLEM.
*
       SIMULATE
*
EXP    FUNCTION   RN1,C24
 Ø,Ø/.1,.1Ø4/.2,.222/.3,.355/.4,.5Ø9/.5,.69
 .6,.915/.7,1.2/.75,1.38/.8,1.6/.84,1.83/.88,2.12
 .9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2/.97,3.5
 .98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9997,8
*
NORM   FUNCTION   RN1,C25
 Ø,-5/.ØØØØ3,-4/.ØØ185,-3/.ØØ621,-2.5/.Ø2275,-2/.Ø6681,-1.5
 .115Ø7,-1.2/.15866,-1/.21186,-.8/.27425,-.6/.34458,-.4.42Ø74,-.2
 .5,Ø/.57926,.2/.65542,.4/.72575,.6/.78814,.8/.84134,1/.88493,1.2
 .93319,1.5/.97725,2/.99379,2.5/.99865,3/.99997,4/1,5
*
       GENERATE   1Ø,FN$EXP              ARRIVING CUSTOMERS
       TRANSFER   BOTH,PHON,WAIT         USE PHONE IF NOT IN USE
WAIT   TRANSFER   .5,LEAV,QUE            HALF DECIDE TO WAIT
LEAV   ADVANCE    5                      GO AWAY FOR FIVE MINUTES
QUE    ADVANCE                           WAIT TIL PHONE AVAILABLE
PHON   SEIZE      PHONE                  START USING PHONE
       ADVANCE    V1
       RELEASE    PHONE                  FINISHED WITH CALL
       TABULATE   1                      GATHER TIME STATISTICS
       TERMINATE  1
*
1      FVARIABLE  8+2*FN$NORM            TELEPHONE CALL TIME
1      TABLE      M1,Ø,5,3Ø              TOTAL TIME DISTRIBUTION
*
       START      1ØØ                    RUN FOR 1ØØ CUSTOMERS
       END
```

SLAM Solution

```
GEN,ARCHER,PHONE PROBLEM,5/3/84;
;
;    EXAMPLE PHONE BOOTH PROBLEM
;
LIMITS,1,1,1ØØ;
NETWORK;
      CREATE,EXPON(1Ø.),,1,,1;           CUSTOMERS ARRIVE
      ACT/1,,NNACT(6).EQ.Ø,QUE;          GO TO PHONE IF NOT BUSY
      ACT/2;
      GOON,1;
      ACT/3,,Ø.5,QUE;                    HALF DECIDE TO WAIT
      ACT/4,5.Ø,Ø.5,QUE;                 HALF GO AWAY FOR 5 MINS
QUE   QUEUE(1);                          WAIT FOR PHONE
      ACT/6,RNORM(8.,2.);                TIME SPENT ON PHONE
      COLCT,INT(1),TIME IN SYSTEM,3Ø/Ø/5;  STATS ON SYSTEM TIME
      TERM,1ØØ;                          RUN FOR 1ØØ CUSTOMERS
      ENDNET;
FIN;
```

Faculty of Business
McMaster University

WORKING PAPER SERIES

101. Torrance, George W., "A Generalized Cost-effectiveness Model for the Evaluation of Health Programs," November, 1970.

102. Isbester, A. Fraser and Sandra C. Castle, "Teachers and Collective Bargaining in Ontario: A Means to What End?" November, 1971.

103. Thomas, Arthur L., "Transfer Prices of the Multinational Firm: When Will They be Arbitrary?" (Reprinted from: Abacus, Vol. 7, No. 1, June, 1971).

104. Szendrovits, Andrew Z., "An Economic Production Quantity Model with Holding Time and Costs of Work-in-process Inventory," March, 1974.

111. Basu, S., "Investment Performance of Common Stocks in Relation to their Price-earnings Ratios: A Text of the Efficient Market Hypothesis," March, 1975.

112. Truscott, William G., "Some Dynamic Extensions of a Discrete Location-Allocation Problem," March, 1976.

113. Basu, S. and J.R. Hanna, "Accounting for Changes in the General Purchasing Power of Money: The Impact on Financial Statements of Canadian Corporations for the Period 1967-74," April 1976. (Reprinted from Cost and Management, January-February, 1976).

114. Deal, K.R., "Verification of the Theoretical Consistency of a Differential Game in Advertising," March, 1976.

114a. Deal, K.R., "Optimizing Advertising Expenditures in a Dynamic Duopoly," March, 1976.

115. Adams, Roy J., "The Canada-United States Labour Link Under Stress," [1976].

116. Thomas, Arthur L., "The Extended Approach to Joint-Cost Allocation: Relaxation of Simplifying Assumptions," June, 1976.

117. Adams, Roy J. and C.H. Rummel, "Worker's Participation in Management in West Germany: Impact on the Work, the Enterprise and the Trade Unions," September, 1976.

118. Szendrovits, Andrew Z., "A Comment on 'Optimal and System Myopic Policies for Multi-echelon Production/Inventory Assembly Systems'," [1976].

119. Meadows, Ian S.G., "Organic Structure and Innovation in Small Work Groups," October, 1976.

Continued on Page 2...

120. Basu, S., "The Effect of Earnings Yield on Assessments of the Association Between Annual Accounting Income Numbers and Security Prices," October, 1976.

121. Agarwal, Naresh C., "Labour Supply Behaviour of Married Women - A Model with Permanent and Transitory Variables," October, 1976.

122. Meadows, Ian S.G., "Organic Structure, Satisfaction and Personality," October, 1976.

123. Banting, Peter M., "Customer Service in Industrial Marketing: A Comparative Study," October, 1976. (Reprinted from: European Journal of Marketing, Vol. 10, No. 3, Summer, 1976).

124. Aivazian, V., "On the Comparative-Statics of Asset Demand," August, 1976.

125. Aivazian, V., "Contamination by Risk Reconsidered," October, 1976.

126. Szendrovits, Andrew Z. and George O. Wesolowsky, "Variation in Optimizing Serial Multi-State Production/Inventory Systems, March, 1977.

127. Agarwal, Naresh C., "Size-Structure Relationship: A Further Elaboration," March, 1977.

128. Jain, Harish C., "Minority Workers, the Structure of Labour Markets and Anti-Discrimination Legislation," March, 1977.

129. Adams, Roy J., "Employer Solidarity," March, 1977.

130. Gould, Lawrence I. and Stanley N. Laiken, "The Effect of Income Taxation and Investment Priorities: The RRSP," March, 1977.

131. Callen, Jeffrey L., "Financial Cost Allocations: A Game-Theoretic Approach," March, 1977.

132. Jain, Harish C., "Race and Sex Discrimination Legislation in North America and Britain: Some Lessons for Canada," May, 1977.

133. Hayashi, Kichiro. "Corporate Planning Practices in Japanese Multinationals." Accepted for publication in the Academy of Management Journal in 1978.

134. Jain, Harish C., Neil Hood and Steve Young, "Cross-Cultural Aspects of Personnel Policies in Multi-Nationals: A Case Study of Chrysler UK", June, 1977.

135. Aivazian, V. and J.L. Callen, "Investment, Market Structure and the Cost of Capital", July, 1977.

Continued on Page 3...

136. Adams, R.J., "Canadian Industrial Relations and the German Example", October, 1977.

137. Callen, J.L., "Production, Efficiency and Welfare in the U.S. Natural Gas Transmission Industry", October, 1977.

138. Richardson, A.W. and Wesolowsky, G.O., "Cost-Volume-Profit Analysis and the Value of Information", November, 1977.

139. Jain, Harish C., "Labour Market Problems of Native People in Ontario", December, 1977.

140. Gordon, M.J. and L.I. Gould, "The Cost of Equity Capital: A Reconsideration", January, 1978.

141. Gordon, M.J. and L.I. Gould, "The Cost of Equity Capital with Personal Income Taxes and Flotation Costs", January, 1978.

142. Adams, R.J., "Dunlop After Two Decades: Systems Theory as a Framework For Organizing the Field of Industrial Relations", January, 1978.

143. Agarwal, N.C. and Jain, H.C., "Pay Discrimination Against Women in Canada: Issues and Policies", February, 1978.

144. Jain, H.C. and Sloane, P.J., "Race, Sex and Minority Group Discrimination Legislation in North America and Britain", March, 1978.

145. Agarwal, N.C., "A Labour Market Analysis of Executive Earnings", June, 1978.

146. Jain, H.C. and Young, A., "Racial Discrimination in the U.K. Labour Market: Theory and Evidence", June, 1978.

147. Yagil, J., "On Alternative Methods of Treating Risk," September, 1978.

148. Jain, H.C., "Attitudes toward Communication System: A Comparison of Anglophone and Francophone Hospital Employees," September, 1978.

149. Ross, R., "Marketing Through the Japanese Distribution System", November, 1978.

150. Gould, Lawrence I. and Stanley N. Laiken, "Dividends vs. Capital Gains Under Share Redemptions," December, 1978.

151. Gould, Lawrence I. and Stanley N. Laiken, "The Impact of General Averaging on Income Realization Decisions: A Caveat on Tax Deferral," December, 1978.

152. Jain, Harish C., Jacques Normand and Rabindra N. Kanungo, "Job Motivation of Canadian Anglophone and Francophone Hospital Employees, April, 1979.

153. Stidsen, Bent, "Communications Relations", April, 1979.

154. Szendrovits, A.Z. and Drezner, Zvi, "Optimizing N-Stage Production/Inventory Systems by Transporting Different Numbers of Equal-Sized Batches at Various Stages", April, 1979.

Continued on Page 4...

155. Truscott, W.G., "Allocation Analysis of a Dynamic Distribution Problem", June, 1979.

156. Hanna, J.R., "Measuring Capital and Income", November, 1979.

157. Deal, K.R., "Numerical Solution and Multiple Scenario Investigation of Linear Quadratic Differential Games", November, 1979.

158. Hanna, J.R., "Professional Accounting Education in Canada: Problems and Prospects", November, 1979.

159. Adams, R.J., "Towards a More Competent Labor Force: A Training Levy Scheme for Canada", December, 1979.

160. Jain, H.C., "Management of Human Resources and Productivity", February, 1980.

161. Wensley, A., "The Efficiency of Canadian Foreign Exchange Markets", February, 1980.

162. Tihanyi, E., "The Market Valuation of Deferred Taxes", March, 1980.

163. Meadows, I.S., "Quality of Working Life: Progress, Problems and Prospects", March, 1980.

164. Szendrovits, A.Z., "The Effect of Numbers of Stages on Multi-Stage Production/Inventory Models - An Empirical Study", April, 1980.

165. Laiken, S.N., "Current Action to Lower Future Taxes: General Averaging and Anticipated Income Models", April, 1980.

166. Love, R.F., "Hull Properties in Location Problems", April, 1980.

167. Jain, H.C., "Disadvantaged Groups on the Labour Market", May, 1980.

168. Adams, R.J., "Training in Canadian Industry: Research Theory and Policy Implications", June, 1980.

169. Joyner, R.C., "Application of Process Theories to Teaching Unstructured Managerial Decision Making", August, 1980.

170. Love, R.F., "A Stopping Rule for Facilities Location Algorithms", September, 1980.

171. Abad, Prakash L., "An Optimal Control Approach to Marketing - Production Planning", October, 1980.

172. Abad, Prakash L., "Decentralized Planning With An Interdependent Marketing-Production System", October, 1980.

173. Adams, R.J., "Industrial Relations Systems in Europe and North America", October, 1980.

Continued on Page 5...

174. Gaa, James C., "The Role of Central Rulemaking In Corporate Financial Reporting", February, 1981.

175. Adams, Roy J., "A Theory of Employer Attitudes and Behaviour Towards Trade Unions In Western Europe and North America", February, 1981.

176. Love, Robert F. and Jsun Y. Wong, "A 0-1 Linear Program To Minimize Interaction Cost In Scheduling", May, 1981.

177. Jain, Harish, "Employment and Pay Discrimination in Canada: Theories, Evidence and Policies", June, 1981.

178. Basu, S., "Market Reaction to Accounting Policy Deliberation: The Inflation Accounting Case Revisited", June, 1981.

179. Basu, S., "Risk Information and Financial Lease Disclosures: Some Empirical Evidence", June, 1981.

180. Basu, S., "The Relationship between Earnings' Yield, Market Value and Return for NYSE Common Stocks: Further Evidence", September, 1981

181. Jain, H.C., "Race and Sex Discrimination in Employment in Canada: Theories, evidence and policies", July 1981.

182. Jain, H.C., "Cross Cultural Management of Human Resources and the Multinational Corporations", October 1981.

183. Meadows, Ian, "Work System Characteristics and Employee Responses: An Exploratory Study", October, 1981.

184. Zvi Drezner, Szendrovits, Andrew Z., Wesolowsky, George O. "Multi-stage Production with Variable Lot Sizes and Transportation of Partial Lots", January, 1982.

185. Basu, S., "Residual Risk, Firm Size and Returns for NYSE Common Stocks: Some Empirical Evidence", February, 1982.

186. Jain, Harish C. and Muthuchidambram, S. "The Ontario Human Rights Code: An Analysis of the Public Policy Through Selected Cases of Discrimination In Employment", March, 1982.

187. Love Robert F., Dowling, Paul D., "Optimal Weighted ℓ_p Norm Parameters For Facilities Layout Distance Characterizations", April, 1982.

188. Steiner, G., "Single Machine Scheduling with Precedence Constraints of Dimension 2", June, 1982.

189. Torrance, G.W. "Application Of Multi-Attribute Utility Theory To Measure Social Preferences For Health States", June, 1982.

190. Adams, Roy J., "Competing Paradigms in Industrial Relations", April, 1982.

191. Callen, J.L., Kwan, C.C.Y., and Yip, P.C.Y., "Efficiency of Foreign Exchange Markets: An Empirical Study Using Maximum Entropy Spectral Analysis." July, 1982.

192. Kwan, C.C.Y., "Portfolio Analysis Using Single Index, Multi-Index, and Constant Correlation Models: A Unified Treatment." July, 1982

193. Rose, Joseph B., "The Building Trades - Canadian Labour Congress Dispute", September, 1982

194. Gould, Lawrence I., and Laiken, Stanley N., "Investment Considerations in a Depreciation-Based Tax Shelter: A Comparative Approach". November 1982.

195. Gould, Lawrence I., and Laiken, Stanley N., "An Analysis of Multi-Period After-Tax Rates of Return on Investment". November 1982.

196. Gould, Lawrence I., and Laiken, Stanley N., "Effects of the Investment Income Deduction on the Comparison of Investment Returns". November 1982.

197. G. John Miltenburg, "Allocating a Replenishment Order Among a Family of Items", January 1983.

198. Elko J. Kleinschmidt and Robert G. Cooper, "The Impact of Export Strategy on Export Sales Performance". January 1983.

199. Elko J. Kleinschmidt, "Explanatory Factors in the Export Performance of Canadian Electronics Firms: An Empirical Analysis". January 1983.

200. Joseph B. Rose, "Growth Patterns of Public Sector Unions", February 1983.

201. Adams, R. J., "The Unorganized: A Rising Force?", April 1983.

202. Jack S.K. Chang, "Option Pricing - Valuing Derived Claims in Incomplete Security Markets", April 1983.

203. N.P. Archer, "Efficiency, Effectiveness and Profitability: An Interaction Model", May 1983.

204. Harish Jain and Victor Murray, "Why The Human Resources Management Function Fails", June 1983.

205. Harish C. Jain and Peter J. Sloane, "The Impact of Recession on Equal Opportunities for Minorities & Women in The United States, Canada and Britain", June 1983.

206. Joseph B. Rose, "Employer Accreditation: A Retrospective", June 1983.

207. Min Basadur and Carl T. Finkbeiner, "Identifying Attitudinal Factors Related to Ideation in Creative Problem Solving", June 1983.

208. Min Basadur and Carl T. Finkbeiner, "Measuring Preference for Ideation in Creative Problem Solving", June 1983.

209. George Steiner, "Sequencing on Single Machine with General Precedence Constraints - The Job Module Algorithm", June 1983.

210. Varouj A. Aivazian, Jeffrey L. Callen, Itzhak Krinsky and Clarence C.Y. Kwan, "The Demand for Risky Financial Assets by the U.S. Household Sector", July 1983.

211. Clarence C.Y. Kwan and Patrick C.Y. Yip, "Optimal Portfolio Selection with Upper Bounds for Individual Securities", July 1983.

212. Min Basadur and Ron Thompson, "Usefulness of the Ideation Principle of Extended Effort in Real World Professional and Managerial Creative Problem Solving", October 1983.

213. George Steiner, "On a Decomposition Algorithm for Sequencing Problems with Precedence Constraints", November 1983.

214. Robert G. Cooper and Ulrike De Brentani, "Criteria for Screening Industrial New Product Ventures", November 1983.

215. Harish C. Jain, "Union, Management and Government Response to Technological Change in Canada", December 1983.

216. Z. Drezner, G. Steiner, G.O. Wesolowsky, "Facility Location with Rectilinear Tour Distances", March 1984.

217. Latha Shanker and Jack S.K. Chang, "The Hedging Performance of Foreign Currency Options and Foreign Currency Futures: A Comparison", March 1984.

218. Ulrike de Brentani and Robert G. Cooper, "New Product Screening Decisions in High Technology Firms: An Empirical Study", March 1984.

219. Paul D. Dowling and Robert F. Love, "Bounding Methods for Facilities Location Algorithms", March 1984.

220. George Steiner, "A Decomposition Approach for Finding the Setup Number of a Partial Order", April 1984.

221. Joseph B. Rose and Gary N. Chaison, "The State of the Unions: United States and Canada", April 1984.

222. Naresh C. Agarwal, "Economic Costs of Employment Discrimination", May, 1984.

223. R.J. Adams, "Estimating the Extent of Collective Bargaining in Canada", May, 1984.

224. Robert G. Cooper, "New Product Strategies: What Distinguishes The Top Performers", May 1984.