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# A SOFT SYSTEMS APPROACH TO INPUT DISTRIBUTION ESTIMATION FOR A NON-STATIONARY DEMAND PROCESS

J. Harold Pardue
Jeffrey P. Landry

Department of Information and Management Sciences
The Florida State University
Tallahassee, Florida 32306-1042, U.S.A.

Thomas D. Clark, Jr.

College of Business Administration
Louisiana State University
Baton Rouge, Louisiana 70803-6302, U.S.A.

## ABSTRACT

A soft systems methodology is undertaken to develop a design for a communications system to support a political campaign. The focus is on the methodology to estimate an input distribution for a SLAM-based simulation model. Two problems--the lack of referent system data and the expectation of non-stationary system demand--indicate a need for a soft systems approach. The results of this study suggest that the approach is effective for estimating an input distribution for simulation analysis. The case provides an example of the contrast between the soft systems and hard systems approaches.

## 1 INTRODUCTION

A SLAM-based model (Pritsker 1986) was developed for simulating a political candidate's communications system. The purpose of the communications system was to automate voice/fax requests for information during the candidate's gubernatorial campaign. The goal of the communications system was to handle all information requests from news media for information about the candidate. The purpose of the simulation project was to ensure the effective and efficient use of system resources. The key problem faced before simulations could be performed was developing an estimate of the system's input distribution. This demand process was estimated using a soft systems approach, combined with the traditional hard systems methodology of simulation.

The purpose of this study is to determine if the methods used are an effective means of estimating an input distribution. If they are, then a broader purpose of this study is to suggest that these methods can enable simulation modeling to proceed towards its goal of analyzing multiple system configurations for effective and efficient resource utilization. The remainder of this paper consists of a contrast between the hard and soft systems approaches, some background data on the referent system and motivation for simulation analysis, a restatement of the research problem, a description of the soft systems approach used in this study, a discussion of the input distribution estimation technique and a post-hoc comparison of the simulation results with actual post-hoc demand data. Some conclusions regarding the effectiveness of the soft systems approach for simulation are drawn.

## 2 HARD VERSUS SOFT SYSTEMS APPROACH

Usually, simulation modeling falls into a category referred to as the hard systems approach to problem solving, an approach rooted in the traditions of positivism, reductionism and determinism (Cavaleri and Obloj 1993). Positivism is a belief that all information about a situation is available, unambiguous and measurable. Reductionism holds that the best way to solve a problem is to break it down into smaller components and solve them. Determinism holds that reality works in a mechanistic fashion and in predictable ways. Hard systems thinking holds that all information necessary can be obtained and used effectively, and that solutions to problems can be found and generalized to a wide variety of situations.

With regard to estimating the input distribution for a simulation model, the hard systems approach is the norm. Analysts often attempt to use standard distributions for estimating inputs in hopes of solving generalized problems (Shanker and Kelton 1991). Another positivistic approach is to collect substantial sample data, which the analyst assumes is available, unambiguous and measurable, and then to use formal statistical methods to estimate an input distribution (Vincent and Kelton 1992). In some situations, however, the assumptions of positivism, reductionism and determinism do not always hold. Sometimes, generalized, standard input distributions are not adequate for modeling system behavior. Hard data on the referent system are often not fully available, unambiguous and measurable. In these situations, a simple, step-by-step solution is not possible, and a softer approach is warranted.

Soft systems thinking is an approach to problem solving that is concerned as much with understanding the problem situation as with solving it (Checkland 1981). It is rooted in relativism and phenomenology. Relativism is a belief that knowledge and wisdom are relevant to a particular situation, and phenomenology holds that knowledge and wisdom are perceptual and subjective--they depend on the observer. Soft systems thinking emphasizes situational factors over generalizability. It is more concerned with the process than structure. Learning is an important phenomenon, as soft systems approaches apply to human systems. A whole stream of management research dealing with the concept of organizational learning incorporates soft systems methodologies to foster shared vision and team learning (Senge 1991), so that organizations of the future can effectively and collectively adapt to a rapidly changing environment.

## 3 COMMUNICATIONS SYSTEM AND THE NEED NEED FOR SIMULATION

The referent communications system was designed to automatically handle incoming voice and fax requests for information, and provide either an automated voice or fax response containing the appropriate information (see Table 1). In many cases, the system would be used to "broadcast" campaign information, not specifically requested, to groups of news media members. The system would reduce or eliminate the personnel normally required to answer phones and send faxes during the busiest part of the campaign. If it worked as planned, the system would provide accurate and efficient handling of all media requests for information. Ultimately, it would contribute to the political objective of enhancing the candidate's pre-election publicity by more widely reaching campaign supporters and the general public.

The goal of the communication system was to handle the expected number of information requests immediately and without delays or busy signals. The purpose of the simulation project was to ensure the effective and efficient use of system resources, so that the goal of the communications system could be achieved within a limited budget. Both over- and under -utilization of resources were undesirable.

Table 1: System Features

| Feature # | Description of Feature |
|---|---|
| 10 | Fax Travel Schedule |
| 15 | Fax Campaign Update |
| 26 | Voice Travel Schedule |
| 30 | Voice Campaign Update |
| 20 | Issue Papers |
| 35 | Leave Voice Message |
| 60 | Group Message to Members |
| 65 | Fax Message to Press |

Based on the estimated non-stationary demand function and the available resources of the system, the following problems were addressed by the simulation model: (1) Can the system handle expected load? (2) How many lines should be devoted to incoming calls and how many to sending out faxes? During peak demand periods and considering the duration of some faxes, not all information requests will be able to be handled immediately. In some cases, the responses will be queued up for later delivery. With regard to these peak demand issues, other research question addressed were (3) How should faxes be scheduled? First-come, first-serve, or shortest job first? and (4) In what situations should a job be interrupted to answer an incoming call? Using SLAM, different configurations of the network system were tested to estimate demand over the 90-day period and determine the utilization of resources.

## 4 RESEARCH PROBLEM — ESTIMATING DEMAND

A necessary step in performing simulation analysis is to develop a valid estimate of the input distribution. Two problems with estimating the input distribution are addressed: (1) no referent system data is available, and (2) knowledge elicited from experts indicate that demand is non-stationary.

The referent system under study--the communications network for handling media requests of a gubernatorial election campaign--fits the soft systems paradigm. Standard input distributions were inadequate for estimating this particular system's demand process. The system had not yet been implemented, and no historical demand data were available upon which a sample could be developed and used to estimate system performance. The demand on the system was expected to be very dynamic over a single 90-day period, making it a transient, rather than a steady-state system (Forrester 1961, Law and Kelton 1991). Validating the simulation model, in the hard systems sense, would be impossible until after the election, when it would no longer be necessary. The only data that were available were ambiguous and not easily measurable--lying in the mental models of the experts in this particular situation. A traditional approach was not possible, and so the question of the appropriateness of simulation was clearly raised.

## 5 APPLICATION OF THE SOFT SYSTEMS APPROACH

Because the nature of the situation fit the soft systems paradigm, a soft systems approach was adopted to better understand: (1) specifically, the expected demand on the communications system, and (2) more broadly, the appropriateness of simulation under conditions of uncertainty. A soft systems methodology known as knowledge elicitation, which consists of a series of open interviews of experts, was used. This technique has been used extensively for requirements analysis during systems development, for knowledge acquisition during expert systems development (Byrd, Cossick and Zmud 1992), and for understanding complex human systems in systems dynamics methodologies (Forrester 1961, Vennix, et al. 1994, Lane 1994). The information possessed by the relevant experts, the campaign committee manager and support personnel, was based on experience and, more importantly, intuition. From a soft systems perspective, the elicitation of an experts' mental models of system behavior can often be an effective means of constructing a simulation model (Burgess, et al. 1992).

One of the researchers conducted interviews with the political campaign committee manager and support personnel, working with them to isolate the most important factors relating to system demand and performance. The clients were encouraged to explain their perceptions of the situation at length, while the researcher took notes and constructed graphical representations of the clients' mental models. The researcher repeated the process several times, each time presenting the clients with an updated model, until a consensus emerged. This is known as the learning approach to information elicitation (Lane 1994). Through an elicitation and representation feedback process, a working model of expectations is iteratively developed.

The collective view of the clients was that demand would gradually increase throughout the 90-day period of its use as the election neared. A key problem was the expectation that the system would initially be overwhelmed with requests when the media was first informed of its availability. To reduce the effects of the flood of first-time callers, the committee planned to inform the media in three separate waves approximately two weeks apart, starting three months before election day when the system went on-line. They hoped this strategy would divide the initial demand into three lesser peaks occurring separately during the first thirty days. Each peak demand period would represent one-third of the news media becoming aware of the system. From the interview process, a graphical representation of this non-stationary demand process (see Figure 1) was developed. This function incorporates a gradual upward linear trend with three early peaks, or "spikes."

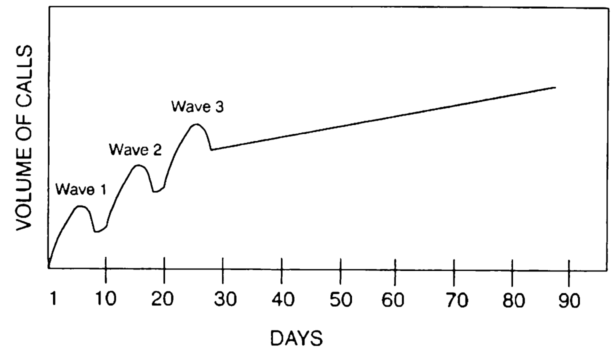


Figure 1: Client's Hypothesized Demand Function

## 6 CONSTRUCTING THE INPUT DISTRIBUTION

A non-stationary demand process corresponding to the graph in Figure 1 was used to simulate the inter-arrival rate of incoming communications requests. This demand process was modeled as a combination of three parabolic trends and an overall linear trend. A look-up table of multipliers was created to fit the parabolic shape of the three peaks. A slope coefficient produced the linear trend. Inter-arrival variation was modeled as a non-stationary mean exponential pattern with the mean of the pattern a function of the time of day.

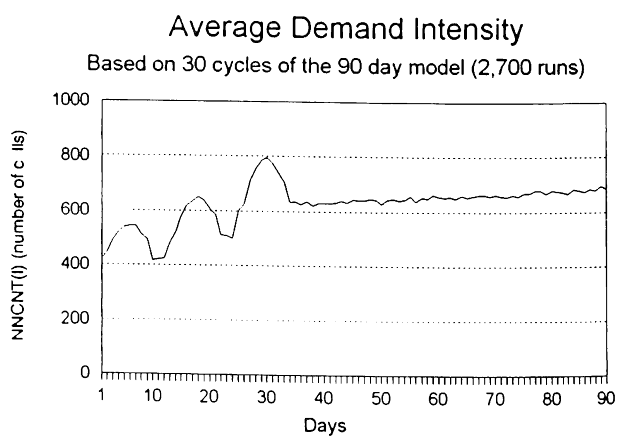

Figure 2: Simulated Demand Function

Time intervals and mean for the arrival distribution were elicited during the interview process. The average demand intensity of the model-generated demand process is graphed in Figure 2. The average values were produced by simulating the model for 30, 90 day cycles.

## 7 SYSTEM AND MODEL STRUCTURE

After a series of iterative interviews, the process converged on a common model of the intended system. The structure of this system is captured in the SLAM model diagram of Figure 3. Initial communication requests arrive according to the demand process generated by USERF(1). At this point, a feature is selected and the request is routed as either a phone feature (20, 26, 30, 35) or fax feature (10, 15) (See Table 1). Without any referent system data, a triangular approach (Law & Kelton 1991) was used to determine the durations for this selection process. During the interview process, estimates of the minimum, maximum, and most likely duration were elicited from the campaign manager and staff. If a phone feature is selected, the request is serviced and exits the system. If a fax feature is selected, the request is routed to the structure labeled "FAX TRANSMISSION." If the necessary resources are not available and a fax request cannot be serviced, a "fax delayed" message is transmitted. The durations for fax transmissions were assumed to have a beta distribution (Law & Kelton 1991) with a uniformly distributed right tail. The general shape of this distribution was elicited from the campaign manager and staff. The beta portion of the distribution was fit using the shape parameters $\alpha_1$ and $\alpha_2$. A listing of the model and FORTRAN user inserts is available from the author.

## 8 ANALYSIS AND RESULTS

Although the simulation model generated daily demand, actual data were collected weekly. This required aggregating model output to weekly sums for the post-hoc comparison with actual data.

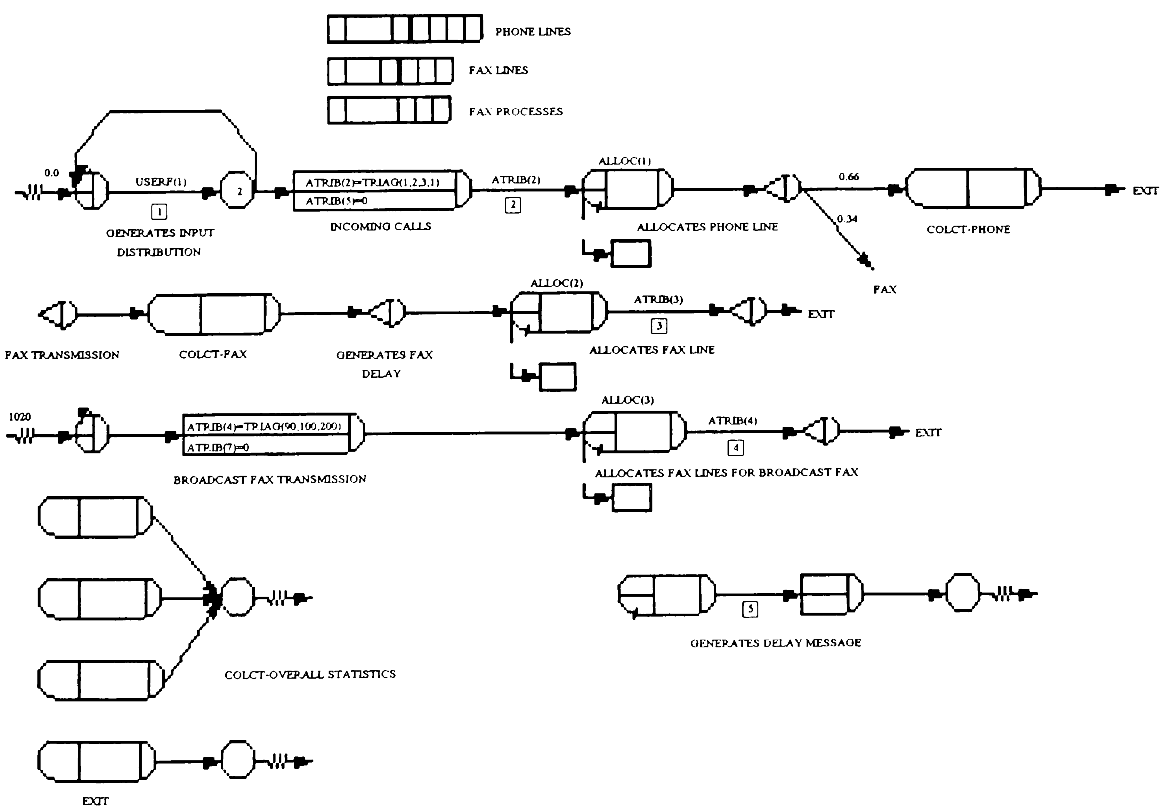


Figure 3: SLAM Model Structure

Three indicators were used to evaluate the degree to which the input distribution generated by the simulation model matched the actual system behavior. The results of this comparison suggest a fairly close match. Each of the three indicators is discussed next.

First, a correlation coefficient for the two sets of data was calculated. The two data sets were found to be significantly correlated at $r = 0.879$ with a two-tailed significance of $p = 0.0000$. This indicates that the model and actual data have a strong positive relationship. Second, the general shape of the simulated input distribution matches the observed demand (see Figure 4). It should be noted that the higher degree of variation exhibited by the actual data can, in part, be explained by the fact that the model-generated data is averaged over 30 runs of the model and the actual data is from a single campaign cycle. Third, and most importantly, the two functions converge toward a common point.

This ultimate convergence of actual system behavior and model-simulated behavior to a common demand volume is important because of the nature of the referent system. An increasing demand function means that peak system demand will occur near the end of the campaign, its most critical juncture. It is at this point that a design tradeoff exists between deficient capacity and excess capacity. In a political campaign, resources must be carefully managed to provide the greatest possible return on investment. A system with deficient capacity would degrade performance when optimal performance is most desired. An excessively redundant system with excess capacity, on the other hand, might assure smooth operations, but would penalize other parts of the campaign by consuming scarce resources. It is, therefore, important to have an accurate estimate of resource demand, especially at the critical peak juncture. The convergence of the demand functions indicates an accurate prediction at this stage.

In addition, the estimate that 34% of incoming calls would result in fax features (10, 15) was in almost exact agreement with the actual data. This accurate prediction is the result of client estimation and further suggests that the knowledge acquisition techniques employed were effective.

## 9 CONCLUSIONS

A relatively high correlation coefficient of 0.879, visual inspection of the shape of the two graphs and graphical convergence indicate that soft systems techniques were effective in determining the input distribution. In situations lacking referent system data, and when the expected system behavior does not fit a known distribution, this study demonstrated that fitting a

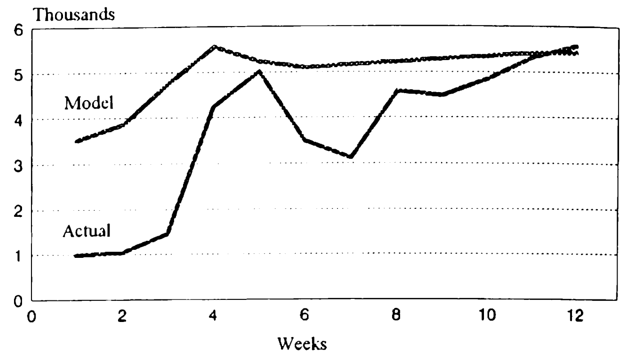


Figure 4: Graphical Comparison of Demand Functions by Week

distribution to the mental models of an expert can be a viable option for analyzing multiple system configurations for effective and efficient resource utilization.

Furthermore, this study has implications for the application of simulation methodology across different situational contexts. Several factors prevented the effective use of strictly hard systems approaches: the lack of referent system data, the ambiguity of expert opinion, measurement difficulties and the randomness of expected system demand. These problems required a soft systems approach to estimating system demand. The success in using a soft systems approach suggests that hard and soft approaches can be combined when situationally necessary, enabling simulation analysis to broaden its application domain.

## REFERENCES

Burgess, G. M. et al. 1992. The Application of Causal Maps to Develop a Collective Understanding of Complex Organizational Contexts in Requirements Analysis. *Accounting, Management and Information Technologies* 2,3: 143-164.

Byrd, T. A. et al. 1992. A Synthesis of Research on Requirements Analysis and Knowledge Acquisition Techniques. *MIS Quarterly* 16:117-138.

Cavaleri, S., and K. Obloj. 1993. *Management Systems: A Global Perspective*. Belmont, California: Wadsworth, Inc.

Checkland, P. 1981. *Systems Thinking, Systems Practice*. New York: John Wiley and Sons.

Forrester, J. W. 1961. *Industrial Dynamics*. Cambridge, Massachusetts: The MIT Press.

Lane, D. C. Modeling as Learning: A Consultancy Methodology for Enhancing Learning in Management Teams. 1994. in Morecroft and Sterman, *Modeling for Learning Organizations*. Portland, Oregon: Productivity Press.

Law, A. M., and W. D. Kelton. 1991. *Simulation Modeling and Analysis*. New York: McGraw-Hill, Inc.

Pritsker, A. A. B. 1986. *Introduction to Simulation and SLAM II*. 3rd ed. West Lafayette, Indiana: Systems Publishing Corporation.

Senge, P. M. 1991. *The Fifth Discipline*. New York: Doubleday/Currency.

Shanker, A. and W. D. Kelton. 1991. Empirical Input Distributions: An Alternative to Standard Input Distributions in Simulation Modeling. In *Proceedings of the 1991 Winter Simulation Conference*, 978-985. Institute of Electrical and Electronics Engineers, San Francisco, California.

Vennix, A. M. and J. W. Gubbels. 1994. Knowledge Elicitation in Conceptual Model Building: A Case Study in Modeling a Regional Dutch Health Care System. in Morecroft and Sterman, *Modeling for Learning Organizations*, Portland: Productivity Press.

Vincent, S. G. and W. D. Kelton. 1992. Distribution Selection and Validation. In *Proceedings of the 1991 Winter Simulation Conference*, 300-304. Institute of Electrical and Electronics Engineers, San Francisco, California.

## AUTHOR BIOGRAPHIES

**J. HAROLD PARDUE** is a Ph.D. candidate in the Department of Information and Management Sciences at the Florida State University. He received his M.C.I.S and a B.A. in Philosophy from the University of South Alabama. His research interests are in the areas of industry-level IT commercialization, CIS curriculum development, the application of psychological type theories to CIS group problem solving, and computer simulation modeling. His research has been published in the *Journal of Computer Information Systems*, *Proceedings of the Association for Information Systems*, *Proceedings of the Decision Sciences Institute*, *Proceedings of the Conference of the Association of Management*, and *Proceedings of the Southeast Regional ACM Conference*. He is a member of INFORMS.

**JEFFREY P. LANDRY** is a doctoral student in the Department of Information and Management Sciences at the Florida State University. He received his M.B.A. and a B.S. in Computer Science from the University of New Orleans. He has seven years of professional experience in software development and project management. His current research interests involve the behavioral aspects of the software development process, particularly dealing with the conflict resolution process.

**THOMAS D. CLARK, JR.** is Professor and Dean of the College of Business Administration at Louisiana State University. He holds the Doctor of Business Administration from The Florida State University, the Masters of Business Administration from Arizona State University and an AB in Biological Sciences from Mercer University. He has extensive operational, management and consulting experience in government and business management and policy development. His current research involves study of multicultural issues in information systems design and operation, the nature and evolution of decision support systems, the value of information in decision processes, performance evaluation and measurement, the effects of outsourcing on information system functions and the effects of technology on work groups and organizations. His research has been published in *Communications of the ACM*, *Decision Sciences*, *System Dynamics Review*, *The Policy Studies Journal*, *Systems Research*, *Simulation*, *The Public Administration Review* and *Behavioral Science*. He is Associate Editor for Information Systems for the *System Dynamics Review* and is on the editorial board of the *Quality Management Journal*.