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SIMULATING OUTPATIENT OBSTETRICAL CLINICS

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ABSTRACT

Computer simulation is a useful tool for addressing resource allocation problems in outpatient obstetrical clinics. We present a general framework for modeling such clinics for the purpose of exploring questions related to demand, appointment scheduling, exam room allocation, patient flow patterns and staffing. Modeling challenges are identified and solutions suggested. Examples from a project completed by the authors at a large obstetrical clinic are used to illustrate the concepts.

1 INTRODUCTION

Outpatient obstetrical clinics provide a range of obstetrical services including pregnancy testing, routine obstetrical visits, and acute obstetrical visits. Appropriate allocation of clinic resources can have a significant effect on cost, quality of care, and patient satisfaction. Important resources for which allocation decisions must be made include staffing (physicians, nurse practitioners, nurses, other support staff), exam rooms, and available appointment slots. Clinical resource allocation problems can be decomposed into four related components: demand forecasting, practice pattern analysis, facility sizing, and staffing. Our focus in this paper is on the use of discrete event computer simulation to support decisions related primarily to facility sizing and staffing. The impact of both demand and clinical practice patterns on facility sizing and staffing can be assessed via simulation modeling as they play important roles in estimation of key model inputs such as visit rates and exam duration.

The complexity of outpatient clinics makes simulation an attractive complement to analytical models. Features of these systems which can be difficult to model analytically include time of day and day of week dependencies in both demand and capacity, scheduled arrivals, and complex patient routings and associated resource use. Simulation provides a modeling approach that can accommodate such complexities relatively easily. Kalton et al. (1997) and Allen et al. (1997) both describe applications of simulation to operational problems involving clinics. In the next section we provide a framework for simulating outpatient obstetrical clinics. We identify challenges and share modeling approaches which are intended to maximize the flexibility and "generic nature" of obstetrical clinic models, thus making it easier to model a wide variety of systems with few structural model changes. Included are discussions of input and output data management issues as these are critical to maximizing the usefulness and effectiveness of clinic simulation models.

2 MODELING OUTPATIENT OBSTETRICAL CLINICS

2.1 Overview

Simulation models are useful for exploring the complex relationships between: patient volume, physician staffing, support staffing, appointment scheduling policies, exam room allocation to providers, patient flow patterns and system performance measures such as: appointment lead time, wait time to see the provider, total patient time in clinic, exam room utilization, physician and support staff utilization, length of the clinic day. Conceptually, an outpatient clinic model can be viewed as three related sub-models: demand generation, appointment scheduling, and clinic operations.

A model of daily clinic operations is useful for exploring questions such as how long patients will wait in the waiting room and to what extent physicians are utilized under different care path scenarios or different numbers of exam rooms allocated to each provider. Demand and appointment scheduling models are needed to answer questions related to the volume of demand for appointments, the queue length and wait time to secure an appointment slot, capacity as measured in available appointment slots and appointment scheduling policies. There is significant interaction between the three sub-models. Assignment of appointment slots is related to the underlying demand for appointments as well as the number, timing, and duration of appointment slots available. Daily arrivals to the clinic are affected by the number, timing and duration of appointments as well as by urgent care demand. We discuss these and other interactions below. Examples from an obstetrical outpatient clinic simulation modeling project completed by the authors will be used to illustrate many of the concepts.

Demand generation involves both demand for clinic appointments and acute care urgent visits and is related to the needs of the underlying service area population. The service area population may be sub-classified into a small number of distinct patient types having different rates of demand for appointments as well as for urgent visits. For example, a typical obstetrical clinic might be well represented by the patient types listed in Table 1.

Appointment scheduling refers to *appointment templates*, provider staffing and the procedures by which appointment slots are allocated to meet patient demand. Appointment templates are a commonly used appointment scheduling tool which specify the number and duration of each available appointment slot for each provider. This component is critical to clinic performance as it essentially specifies a large part of total available capacity and thus affects clinic congestion and access to clinic appointments. See Ho and Lau (1992) for a comprehensive review and analysis of analytical modeling of appointment systems.

Table 1: Patient Types

	Patient Type
1	Routine Follow-Up
2	Pregnancy Testing
3	Prenatal Registration
4	First Prenatal Visit
5	Postpartum
6	Complicated OB / Adolescent
7	Diabetic
8	Acute OB

The clinic operations sub-model refers to the actual events that occur during the course of a patient's visit to the clinic. This includes the areas visited within the clinic and the duration of time spent with various providers and support staff.

Figure 1 presents a high level view of the outpatient obstetrical clinic model. Demand for appointments are generated from the underlying population. An appointment slot is assigned based on the appointment templates as well as the specific appointment scheduling practices and

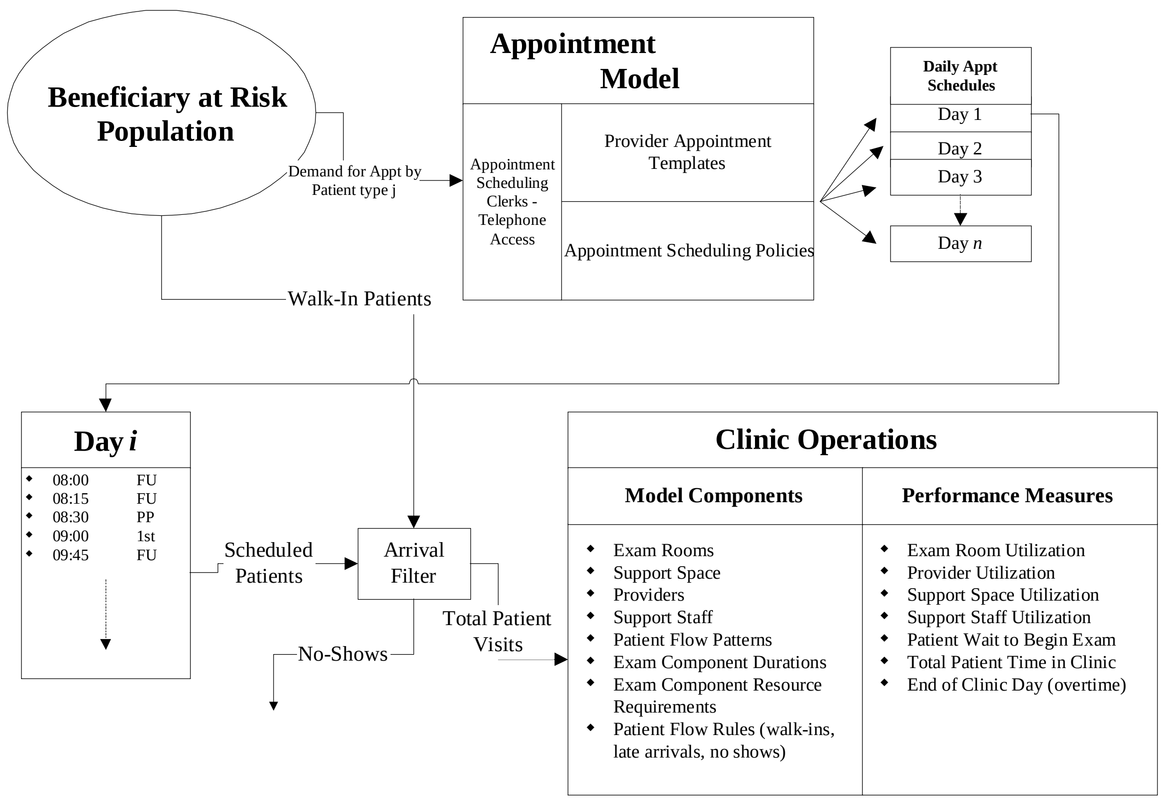

Figure 1: Obstetrical Clinic Model

policies in place. This results in a set of clinic appointments for each day. These daily appointment schedules serve as the mechanism for generating arrivals to the clinic each day. A stream of urgent care demand is superimposed upon the scheduled demand to create the total composite stream of arrivals to the clinic. The clinic sub-model then captures the details of each patient's visit to the clinic.

2.2 Modeling Demand

Since the population being served is large in relation to the number of appointments per day, it seems reasonable to model the *demand for appointments* by a Poisson process. We are not suggesting that all arrivals to a clinic on a given day should be modeled as a Poisson process. We are arguing that demand for each appointment type can be characterized by an underlying mean demand rate and that the probability distribution of the number of appointment requests arriving in any interval of time (e.g. per day or week) is adequately represented by a Poisson distribution. If detailed data is available, this hypothesis can be tested statistically and if rejected, an alternative theoretical or empirical distribution constructed. However, if only summary data, such as appointments scheduled per month, is available, then use of the Poisson process model is a convenient approach which seems intuitively reasonable. If the underlying demand rate is changing (e.g. growth or seasonality trends), a non-homogeneous Poisson process can be used to model such effects (see Law and Kelton 1991).

A modeling decision must be made related to whether the atomic level of demand is a single appointment request or a sequence of appointments for the same patient. Most prenatal patients will have a sequence of increasingly more frequent visits as the pregnancy progresses. Data limitations may prevent the use of a sequence of visits as the atomic level of demand for routine prenatal visits. In our project, we used individual appointment requests as only aggregate volume data was available.

One must be careful to differentiate between demand for appointments and actual visits. Actual visit volume by day of week and time of day is directly related to the configuration of available capacity: hours of operation of the clinic, clinic staffing patterns, and appointment templates. At an aggregate level, the number of actual visits is affected by urgent care patients, cancellations, no-shows, and perhaps unmet demand (patients who choose to go elsewhere due to lack of appointment capacity or other reasons). At a capacity constrained facility, urgent care volume may be partially due to the difficulty of obtaining an appointment. If we denote the total visit rate by V, the scheduled visit rate by S, the urgent care visit rate by U, then $V=S+U$. Also, scheduled visits can be decomposed into scheduled appointments (A), cancellations (C) and no-shows (N), by $S=A-(C+N)$. Causal or time-series based forecasting techniques could be used to develop forecasts of A, U, C and N for each appointment type.

Urgent care demand can also be modeled as a Poisson process. If detailed data exist such as the actual date and time of the arrival of urgent care patients, a non-homogeneous Poisson process can be used to capture day of week and time of day differences in the arrival rates of different urgent care patient types. At a minimum, urgent care visits can only occur during the hours of operation of the clinic. Be aware that insufficient appointment slot capacity may also affect urgent care rates.

The result of an exercise in demand modeling would be something on the order of Table 2. For each patient type we have an estimate of the rate of requests for appointments as well as an estimate of the urgent care rate. The requests for appointments are arrivals to the appointment scheduling model while the urgent care patients will directly enter the clinic operations model.

Table 2: Demand Summary

Patient Type	Average Weekly Volume Appt. Request (A_i)	Urgent Care (U_i)	Total
Routine Follow-Up	363.5	60.7	424.3
Pregnancy Testing	0.0	98.0	98.0
Prenatal Registration	93.0	0.0	93.0
First Prenatal Visit	56.2	1.5	57.7
Postpartum	21.5	0.3	21.7
COB/Adol.	35.5	0.2	35.6
Diabetic	23.6	0.2	23.8
Acute OB	0.0	54.4	54.4
Total	593.3	215.3	808.5

2.3 Appointment Model

Many discrete event simulation languages are not particularly well suited for modeling the arrival of demand for an appointment and the actual assignment of an appointment slot. As appointment scheduling is very much a database application, we have found it easier to create this model in a database development environment such as Microsoft Access®. The building blocks of appointment schedules are appointment templates. While these may take a number of forms, their basic function is to provide a means for representing the number, duration, and timing of available appointment slots. An example of a typical appointment template is shown in Figure 2.

Template ID:	Phys_Mon_AM_OB		
	Provider Type:	Physician	
Day / Time:	Monday AM		
	Clinic:	OB	

Start Time	Slot Length	Appointment Type	Patients Per Slot
8:30	30	NEW	1
9:00	15	Postpartum	1
9:15	15	Follow Up	1
9:30	15	Follow Up	1
9:45	15	Follow Up	1
10:00	30	NEW	1
10:30	15	Follow Up	1
10:45	15	Follow Up	1
11:00	15	Follow Up	1
11:15	15	Follow Up	1
11:30	15	Follow Up	1

Figure 2 : Appointment Template

This template is for physicians on a specific day of the week (Monday) and time of day (morning) in the general OB clinic. Each appointment slot is defined by its start time, slot length (in minutes) and appointment type. Typically, appointments are classified into a small number of distinct types based on the resources such as time, staff, or equipment needed. Classification into a small number of demand types adds modeling flexibility and is a better representation of reality than a single aggregate appointment type.

Appointment slot types may be mapped one to one with the patient types or a single appointment type may include multiple patient types. For example, Follow-Up and Postpartum could be combined into a single appointment type called Routine. The modeling of appointment templates can get quite complex and tedious as there may be a large number of distinct templates. In this project, there were forty-six different aggregate appointment templates. Each aggregate template was for one or more specific providers and was defined by the type of provider (physician, nurse practitioner, prenatal nurse or resident), the day of the week, morning or afternoon, and the specific specialty clinic (routine, complicated, or diabetic obstetrical). The forty-six aggregate templates grew to several hundred when duplicated for each specific provider. Database technology is a tremendous aid in generating and managing the individual templates.

The design of appointment templates is a difficult problem for which simulation can provide some aid by serving as a vehicle for testing proposed designs. Designing templates involves determining the number, duration and sequencing of different appointment types and depends on the forecasted demand for each patient type. The design is also affected by the number of exam rooms allocated to each physician as a physician with two exam rooms should be able to accommodate a larger number of appointments per day than a physician with a single exam room. The interaction between the number of exam rooms per physician and the optimal design of appointment templates presents difficult stochastic combinatorial problems that have not been addressed analytically to our knowledge.

Creating realistic appointment schedules is a critical component of a clinic simulation model if one is interested in questions related to how different appointment template designs and appointment scheduling policies affect access to the clinic and the clinic operations themselves. Operational logic is needed to actually assign a specific appointment slot to the patient requesting the appointment. A simple approach is to assume that each appointment request is given the first available appointment slot of the appropriate type and for the requested provider. More complex logic is needed to handle cases in which appointments are for any member of a team of providers or situations other than assigning the first available slot are to be modeled. An objective may be to assess how well alternative appointment systems meet the needs of its customers with respect to assigning an appointment slot which is as close as possible to the date and time requested. In this case, one needs a method for representing the distribution of requested appointment dates by patient types. The above concerns lead to the conclusion that modeling such complexity requires a general purpose programming language (either as part of a dedicated discrete event simulation program or a general purpose tool such as Visual Basic®). If exploration of alternative template designs is to be practical, automated methods for creation of the appointment templates and appointment schedules is essential.

In our project, we took a relatively simple approach to creating realistic appointment schedules without going to the effort of creating software machinery to dynamically fill schedules based on the templates and a stochastic stream of arriving appointment requests. The appointment templates were obtained from the facility. These templates, along with a staffing summary which specified the number of providers accepting appointments each day, allowed us to create a "fully loaded" one week appointment book to serve as input to the daily clinic model. The elements included in the appointment book were a unique patient identifier, provider identification number, exam day and time, scheduled exam length, and patient type indicator. The fully loaded appointment book was generated with a database application and exported as a delimited text file (containing 960 appointments) to be read by the clinic operations model. It was converted into an ongoing stream of arrivals to the daily clinic model by using *effective* *vacancy rates* as a filter to probabilistically create realistic daily schedules that varied from week to week. The effective vacancy rate is an estimate of the percentage of appointment slots that go unused due to cancellations, no-shows, or slots that never had a scheduled appointment. Even if detailed cancellation or no-show data is unavailable, the effective vacancy rate can be inferred from the total number of visits (by patient type), the percentage (by patient type) of the total visits which were urgent care visits, and the total available appointment capacity by patient type (which can be determined from the templates and the staffing summary.) Effective vacancy rates can be estimated for each appointment type and then used to probabilistically reject arrivals from the fully loaded appointment schedule. The result is a set of daily schedules that vary from day to day and week to week. While this approach is relatively simple, it prevented us from exploring questions related to the dynamics of requests for and filling of appointment slots.

2.4 Clinic Operations Model

The purpose of the clinic operations sub-model is to simulate the arrival of scheduled and urgent care patients to the clinic and their subsequent sequence of encounters with providers of care. Resources which are likely candidates for inclusion in the clinic operations model are physicians, nurse practitioners, residents, support staff (nurses, medical technicians, and front office personnel), exam rooms, special purpose areas (e.g. specimen collection), and waiting areas. Depending on the simulation tool used, it may be a challenge to model staffing levels that change by day of week and time of day.

2.4.1 Arrivals

As mentioned previously, arrivals to the clinic operations model are a combination of urgent care patients and scheduled patients. The arrivals of the scheduled patients are controlled by the daily appointment schedules created by the appointment model while the urgent care patients can be generated within the clinic operations model. It is easy to model increases in scheduled visit volume without modifying the appointment templates by reducing the effective vacancy rates. Patient punctuality can be modeled by altering the actual arrival time to the clinic by a random (positive or negative) quantity. This can be done within the clinic operations model if each day's appointment schedule is read in at the beginning of the day and each patient "delayed" until their actual arrival to the clinic.

2.4.2 Visit Flow Development

For each patient type one can develop a detailed *visit flow diagram* (VFD). The visit flow diagram specifies the sequence of locations visited, the resources required at each location and the duration of time spent in each stage. The VFD in Figure 3 is for Routine Follow-Up patients. Each numbered block documents a stage in the patient path. Four different block types are shown: Process, Transport, Wait, and Arrival/Exit. Each block type has one or more relevant block attributes. For example, Process blocks have a resource, duration, and keep resource attributes. The resource attribute specifies the staffing resource needed (if any) to perform this process. For the duration attribute, a probability distribution is listed. In the Figure, generic names such as pdf_ExamConsult are shown though actual fitted distributions and associated parameter values could be included as well. For duration attributes at Transport blocks, the value is indicated as being "distance based" to indicate that the travel time will be determined at model run time based on the scaled floorplan, the specific route taken by the patient, and the travel rate. The free resource attribute is a binary variable which indicates whether or not the patient releases the resource after the process is completed. The visit flow diagram essentially determines the level of detail at which the clinic visit is modeled. For example, the time spent with the physician was modeled as an interval time of some stochastic duration as opposed to different distributions for each sub-task performed by the physician with the patient (e.g. history and physical, pap smear, etc.). A VFD is more detailed than a basic flow chart but is not quite pseudo-code. It provides a framework for defining, verifying and documenting patient flows and makes it relatively easy to develop the logic and write the actual simulation code.

2.4.3 Data Input Files

As part of enforcing separation of the the model from scenario specific data, external text, spreadsheet or database files can be used to store parameter values and then can be read by the model for instantiation. The parameter files include data specifying the appointment schedules, arrival rates for urgent care patients, provider staffing levels and effective vacancy rates. One of the challenges involved in modeling outpatient clinics is in handling the assignment of specific exam rooms to specific providers as such assignments are typically dynamic throughout the week. We modeled the situation by creating a matrix, stored in an external file, which indicated the identification number of the provider assigned to each exam room for each clinic period (each day of the week was divided into a morning, afternoon, and evening period, for a total of twenty-one clinic periods in a week). The data was stored in an array within the model and was accessed to ensure patients were routed to an appropriate exam room based on their provider and time of day. Database and spreadsheet technology can be exploited to create the

#	Location	Block Type	Block Detail
0	*Registration*	Arrival	Scheduled
1	*Registration*	Wait	Get AdminSupportStaff
		Resource	None
2	*Registration*	Process	Check in
		Resource	AdminSupportStaff
		Duration	pdf_Registration
		Free Resource	Yes
3		Transport	Move to Restroom
		Resource	No
		Duration	Distance Based
4	*Restroom*	Process	Specimen Collection
		Resource	None
		Duration	pdf_SpecimenCollection
		Free Resource	None
5		Transport	Move to Spec. Collection
		Resource	No
		Duration	Distance Based
6	*Specimen*	Process	Specimen Drop-off
		Resource	None
		Duration	pdf_SpecimenDropOff
		Free Resource	None
7		Transport	Move to Waiting Room
		Resource	None
		Duration	Distance Based
8	*Waiting Room*	Wait	Get MedSupportStaff and Vitals Station
		Resource	None
9		Transport	Move to Vitals Station
		Resource	MedSupportStaff
		Duration	Distance Based
10	*Vitals Station*	Process	Vital Signs
		Resource	MedSupportStaff
		Duration	pdf_VitalSigns
		Free Resource	Yes

#	Location	Block Type	Block Detail
11		Transport	Move to Waiting Room
		Resource	None
		Duration	Distance Based
12	*Waiting Room*	Wait	Get Exam Room and MedSupportStaff
		Resource	None
13		Transport	Move to Exam Room
		Resource	MedSupportStaff
		Duration	Distance Based
		Free Resource	No. Keep MedSupportStaff
14	*Exam Room*	Process	Exam Prep
		Resource	MedSupportStaff
		Duration	pdf_ExamPrep
		Free Resource	No
15	*Exam Room*	Wait	Get Provider
		Resource	None
16	*Exam Room*	Process	Examination
		Resource	Provider + MedSupportStaff
		Duration	pdf_ExamRoutine
		Free Resource	MedSupportStaff
17	*Exam Room*	Process	Post Examination Consult
		Resource	Provider
		Duration	pdf_ExamConsult
		Free Resource	Yes. Patient takes chart.
18		Transport	Move to Check Out
		Resource	None
		Duration	Distance Based
		Free Resource	None
19	*Check Out*	Wait	Get MedSupportStaff
		Resource	None
20	*Check Out*	Process	Check Out
		Resource	MedSupportStaff
		Duration	pdf_CheckOut
		Free Resource	Yes
21	*Check Out*	EXIT	

Figure 3: Visit Flow Diagram

software machinery needed to generate and manage the data input files. These tools can also be used to create user-friendly front ends to facilitate input file creation. For example, we created a form which allowed the user to set values for a number of key model variables and then push a button to generate the associated data input files.

2.4.4 Log Files

Simulation development environments differ with respect to their level of output analysis tools included. We have found it is usually worth the effort to create detailed log files during simulation run time and to process these output files using database and spreadsheet packages. In our outpatient clinic model, three log files are created: a visit path log, location log, and a resource log.

The visit path log contains one record per patient visit comprised of a combination of attributes of the patient's visit and a series of date/time stamps marking important epochs in the visit. The visit attributes include a unique patient identification number, appointment date/time, provider identification number, patient type, scheduled exam length, and the exam room number. The date/time stamps include arrival to the clinic, begin check-in, end check-in, begin prep phase of exam, end prep phase of exam, enter exam room, exit exam room, begin provider phase of exam, end provider phase of exam, begin check-out and end check-out. The visit log facilitates analysis of the amount of elapsed time between various epochs for each patient type and obviates the need to create a large number of variables to be tracked within the simulation model.

The location log contains a record each time a location of interest is visited in the clinic. Each record contains a location identifier, a unique patient identifier, and the date/time stamps for the entry to and exit from the location. This log file makes it very easy to analyze the utilization and probability distribution of occupancy (overall as well as by time of day and day of week) of each location (overall and by patient type). While most simulation packages will automatically collect location utilization statistics, it may not be straight forward to automatically capture such statistics for certain time intervals of the day (clinics are usually not open twenty-four hours per day) or for subsets of different entity types. The resource log is very similar to the location log; it tracks resource use such as physicians and support staff. Note that it is also possible to analyze the sequence of locations visited and resources used by each patient from the information contained in these two log files.

3 CONCLUSIONS

We have outlined a general framework for simulating outpatient obstetrical clinics. Our intent has been to provide would be modelers of clinics a starting point and a reference for guiding the model development process. The specific questions for which the model is being built will affect its detailed design more than anything else. The clinic model has been presented as three related sub-models: demand, appointment scheduling, and clinic operations. Each of these three models, as well as their interactions, presents a number of modeling challenges for which we have tried to give some direction. These include characterizing demand, creating appointment schedules, superimposing urgent care demand on scheduled appointments, developing patient flows, allocating specific exam rooms to specific physicians, and creating detailed output log files to facilitate analysis. Many of the ideas in this work should apply to outpatient clinics in general.

REFERENCES

Allen, P.O., Ballet, D.W., and G. Kimball, Simulation Provides Surprising Staffing and Operation Improvements at Family Practice Clinics, *HIMSS Proceedings*, (1997) 212-227.

Ho C.-J., and H.-S. Lau, Minimizing Total Cost in Scheduling Outpatient Appointments, *Management Science*, 38, 12, (1992), 1750-1764.

Kalton, A.G., Singh, M.R., August, D.A., Parin, C.M., and E.J. Othman, Using Simulation to Improve the Operational Efficiency of a Multi-Disciplinary Clinic, *Journal of the Society for Health Systems*, 5, 3, (1997) 43-62.

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

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