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Simulating service systems

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1. Introduction and Overview

During the last two decades, the service sector has shown a remarkable growth in different aspects of both national and international economies. Service companies such as banking, hospitality, restaurants, health systems, telecommunication, transportation, and insurance industry play a major role in today's market. As a result, many engineering techniques, analytical methods, and software tools were developed to help designing service systems, solving problems in their operation, and optimizing their performance. In such context, simulation is a key engineering tool that is widely used for the analysis of service systems.

Simulation modeling is an engineering tool that has been widely used in both service and manufacturing systems applications. Simulation has been utilized to model banks, fast food restaurants, computer systems, telecommunication networks, health clinics, traffic and transportation, logistics, airports, post offices, and many other service systems. Simulation has been also used in modeling business operations such as product development processes, manpower planning, financial transactions, data processing, and information flow.

Similar to manufacturing systems, service systems provide one or more service/processing to flowing entities (for example, customers) through system resources and operations. Entities are routed through a sequence of processing operations/stations at which system resources such as employee or automatic processing machines provide the required service. The resemblance between service and manufacturing should not preclude the analyst from recognizing and taking into consideration the unique characteristics of service systems. Unlike physical products, services are often intangible, difficult to be put in storage, their outputs are hard to measure and quantify, and highly impacted by human behavior.

With the flexibility of simulation software, however, many of service systems characteristics can be captured in a computer model that behaves almost similar to a real-world service system. As a result, simulation modeling has become a popular management Decision Support System (DSS) tool for planning, improvement, and problem-solving. In the context of service systems, simulation is used to study the service system behavior, quantify the provided service, compare proposed alternatives for providing services, improve service level, better utilize resources, reduce service time and cost, and setup/configure the service system to provide the best performance possible within given business constraints.

Example of industries who can benefit from service system simulation:

- Healthcare and hospital management
- Hospitality and hotel management
- Banking and finance
- Supply chain and logistics
- Warehousing and storage systems
- Airports and aviation
- Traffic and transportation systems
- Restaurants and food services
- Postal services
- IT systems, communication networks, and data flow

Examples of objectives or benefits of simulating service systems:

- Optimize asset management
- Increase productivity
- Analyze and optimize supply chain and logistics
- Forecast demand and predict performance
- Increase upstream profitability
- Design, plan, and manage operations
- Optimize resource reallocations
- Identify and resolve bottlenecks
- Analyze alternative work processes
- Test the effect of alternative layouts
- Facilitate and support decision making
- Address risks and vulnerabilities

Examples of performance measures used to assess the performance of service systems:

- Throughout
- Utilization and efficiency
- Waiting time and overall lead time
- Consistency
- Waste, errors, and rework
- Cost and profit

This chapter presents the basics of service system simulation with application case studies. It first identifies and defines the main elements of service systems. It discusses the modeling techniques used in developing Discrete Event Simulation (DES) models of service systems. It also presents the Key Performance Indicators (KPIs) that can be used to measure and assess the performance of service systems. Finally, example case studies are presented.

2. Basics of Service Systems

This section provides the readers with the basic information necessary to understand the nature and functionalities of service systems.

2.1 Elements of Service Systems

Several elements commonly form a service system in various sectors of service industry. Such elements include wide range varieties in types and applications. Understanding such

elements is essential to building simulation models that represent service systems. Most service systems involve a process for receiving customers and/or their requests. This process often includes activities such as receiving, registering at the reception, preparation of documents or material, and waiting for service. Service providers take care of customers and their requests by processing orders, serving customers, treating customers, and so on. Other business functions involved in providing services include sales, cashier, data entry, payments, etc. Services also develop and implement a process for service/facility departure. Departure process provides means for checking service/product quality, packaging, shipping, etc. Figure 1 depicts the main elements of a service system:

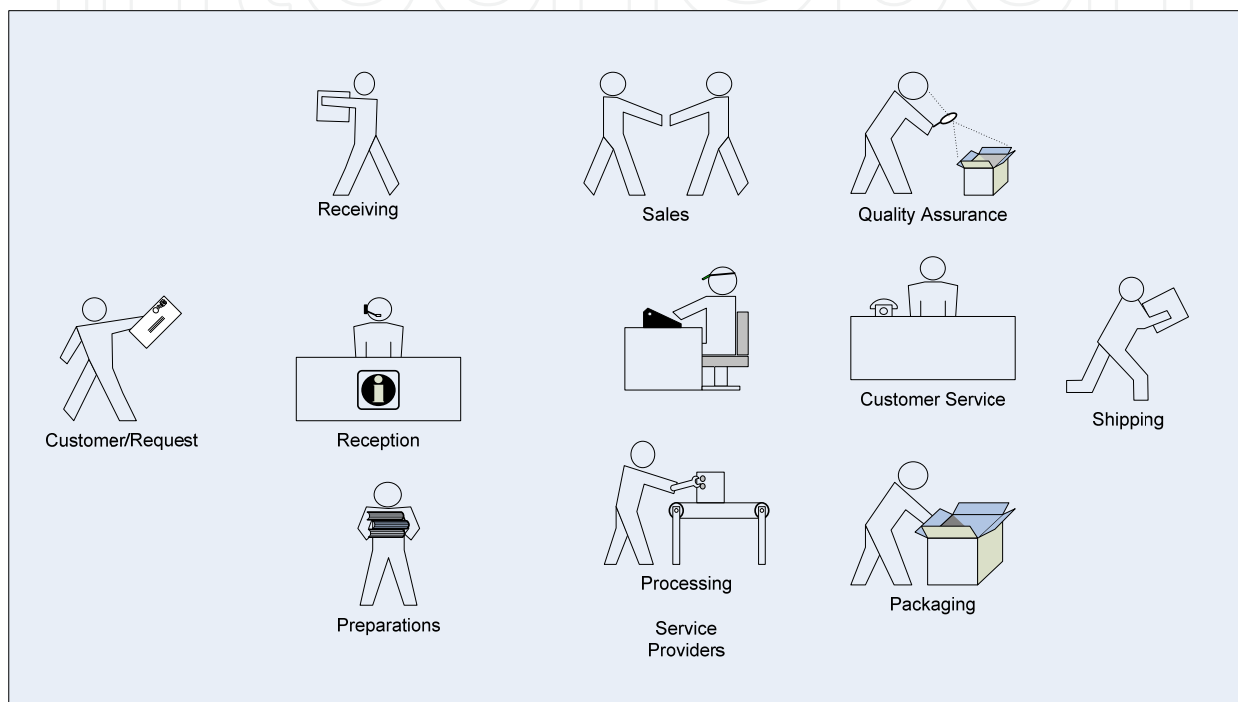


Fig. 1. Elements of a Service System

Other elements may exist in the service system based on its nature and business functions. For examples, a healthcare clinic often involves medical resources (doctors and nurses, X-ray facility, dental care equipment, etc.). A bank often involves tellers, ATM machines, loan officers, and so on. In general, basic building blocks in any service system often include the following:

2.1.1 System Entities

Customers (humans) represent the main entity that flows through various types of service systems. Customers arrive to the service system, request the service, receive the service, and departure the service system. For example, customers arrive to a bank and select/request the kind of service they wish to do such as making deposits, withdrawals, money transfers, and so on. Customers often wait for bank services in queues when the bank tellers are not available. Once a customer gets to the server (bank teller), he/she receives the service (the transaction) and then departs the bank. Other similar examples include patients at a clinic, customers at a fast food restaurant, a checkpoint, a post office, and so on.

In addition to customers, there could be other types of entities in a service system. Such entities are usually initiated by customers such as paperwork in a governmental office, insurance claims in an insurance company, calls in a calling center, and information bytes in a computer network. While the word “service” may not be of a direct meaning with such entities, these entities are processed in order to provide a certain service to the end customers. Such entities are moved in a certain sequence between service areas/stations, where value is added to such entities through processing. Value in such context may refer to percent of completion or benefit obtained from processing stations.

2.1.2 Service Providers

Entities in a service system arrive to the service center, request the service, and wait in front of service providers. Those are the resources through which the requested service is provided. Examples include waitresses in a restaurant, window tellers in a fast food restaurant, bank tellers in a bank, doctors and nurses in a clinic, customs officers at a border-crossing terminal, receptionists in hotels, customer service representatives, and so on.

The capacity of service providers determines the service time (time a customer spends during service) and impacts the waiting time (time customers wait to get to the service providers). Thus, determining the best number of service providers is a key factor in designing service systems. Queuing theory in Operations Research (OR) is typically used to analyze the impact of different number of servers on service time and determine the optimum number of servers. However, not all assumptions are often met in real world applications in order to use the formulas of the queuing model. Simulation modeling, therefore, is often utilized to model the service system and analyze the impact of varying the number of service providers on key system performance measures (KPIs) such as throughput, customer waiting time, and servers’ utilization.

2.1.3 Customer Service

Most service systems include a mean for customer service through which complaints and feedback from customers are received and analyzed. Free of charge telephone numbers, centers of customer service, and though website customer feedback, are common forms of customer service in service systems. In retail stores, customer service allows shoppers to return or replace merchandise, help customer find merchandise, and allows for reporting concerns directly to store management.

The role of customer service is crucial to provide high quality products and services to customers, establish a direct/indirect relationship with customers, retain customers, and gain their trust. A service system with no customer service is similar to an open-loop control system where no feedback signal is fed back into the system controller to adjust its operation. As a result, valuable customer notes and complaints are wasted, service operations are not enhanced to meet customers’ expectations, and consequently some unsatisfied customers will eventually look for service at another place, typically the competition.

2.1.4 Staff and Human Resources

Staff, business managers, and customer service associates are key building block that can greatly contribute to the success or failure of a service system. Most service systems rely on

humans for providing services. For example, no matter how sophisticated and powerful hospital equipment get, hospital doctors and nurses will play the major role in providing medical services. Similarly, we can understand the role of bank tellers, calling officers, and receptionists. Some of those are direct service providers in the front office and some work in the back office.

2.1.5 Service Facility

The layout and the physical structure of the service facility have a special importance in service systems. Designing the facility layout in an effective manner that assists both service providers and customers is often critical to the performance of the service system. Certain safety and operational requirements and construction codes are essential to be met when designing the service facility. Examples include the parking lot, handicapped parking, waiting areas, location of reception and help desks, layout and structure of service areas/station, male and female rest rooms space and capacity, and facility environment such as illumination, air condition, insulation, and heat.

Building codes and standards that are compliant to regulations of cities and provinces provide the specific requirements of service facilities. Such requirements vary based on the service nature. For example, what is required for a gas station and oil change facilities is different from that of banks and restaurants. The interior design of the facility (each area's capacity and features), the organization of the place layout (interdepartmental relationships) and the physical structure of the facility (material and flow of service in the facility) is a combination of art and design, regulations, and business needs.

2.1.6 Operating Policy

Operating policies are also critical component in any service systems. Operation pattern (opening and closing hours), routing customers, flow of each service, queue and service discipline, and departure rules are examples of operating policies. This also extends to what is allowed and not allowed within the facility or during the service, dress code, and accessibility.

2.2 Characteristics of Service Systems

There are several business characteristics that are unique to service systems. One key characteristic of service systems is dealing directly/indirectly with customers. As mentioned earlier, service systems entities are mostly humans or human requests. This requires that the service system to be flexible and agile in order to accommodate varying customer demands and desires. Consequently, service systems are characterized by being highly impacted with customer behavior and the level of customer service. In addition, service operations often involve high variability due to varying customer needs and requests. Providing the service may also require making complex decisions that balance customer service and business interest.

Comparing services to tangible products can help in understanding the nature of service systems. Unlike manufacturing facilities where customers are not directly involved in the process, service systems involve direct interaction with customers to provide them with intangible services or to sell customers tangible products. The performance of systems offering customers intangible services/products can be expressed in terms of effectiveness,

presentation, reliability, and cost. For tangible products we often ask questions about the following:

- Effectiveness: Does the product do its job well?
- Presentation: Does the product look good?
- Reliability: Is the product trouble free?
- Cost: Is the product reasonably priced?

Services are, on the other hand, are slightly different from physical products. For services, we often ask questions differently but on the same quality aspects:

- Effectiveness: Am I getting the right service?
- Presentation: Am I getting the service in a way that appeals to me?
- Reliability: Am I getting the service on time or within acceptable time?
- Cost: Are the service fees reasonable?

In general, the key aspects of service quality often include the following:

- Tangibles: Facility, location, office, etc.
- Convenience: Proximity, parking, services, etc.
- Reliability: Availability, trust, safety, etc.
- Flexibility: Responsiveness, operating pattern, order fulfillment, etc.
- Time: Waiting, processing, schedule, etc.
- Assurance: System, feedback, control, etc.
- Courtesy: Friendliness, smile, experience, etc.

In terms of the process, the flow of services may not be structured such as the case in a manufacturing process. The service specifications may not be also quantified and consistent such as the case in products. This reflects on developing the sequence and the logic of service industry as well as on selecting the Key Performance Indicators (KPIs) to assess and improve the performance of service systems. The amount of variability involved in service operations is higher than that of manufacturing processes. Human performance and effectiveness is different from those of machines and automated assembly lines.

3. Modeling Service Systems

“How to model a service system?” is a question that is frequently asked by simulation analysts. This concern often results from the difficulties modelers have in structuring a service system and in developing a model that accurately resembles the defined structure and logic. This section presents the basic techniques that can be utilized to model service systems.

A generic step-by-step simulation processes such as the one discussed in earlier chapters can be used to simulate service systems as well as other systems. However, experience in modeling service systems often lead to certain modeling considerations that are particularly important to capture the unique characteristics of service systems. Given the discussed elements of service systems, certain set of modeling elements can be used to model service systems. Along with that, and by analyzing the structure of the underlined service system, certain set of model control factors and performance measures can be defined and used to design experiments and optimize the settings of service systems.

3.1 Modeling Considerations

Because of the unique characteristics of service systems, it is typically difficult to prescribe a specific modeling technique to simulate service systems. Instead, the simulation process is adapted to the specifics of the underlying service system. In general, it is recommended to model the service system as a manufacturing system that involves complex manual operations of high variability. Special attention is paid to the sequence and the content of each service process within the system. Certain modeling assumptions are then made to approximate the functionality of these service operations. A generic model of a service system is shown in Figure 2. Similar to queuing models, a model of a service system often involves an arriving process, a waiting discipline, a service process, and a departure process.

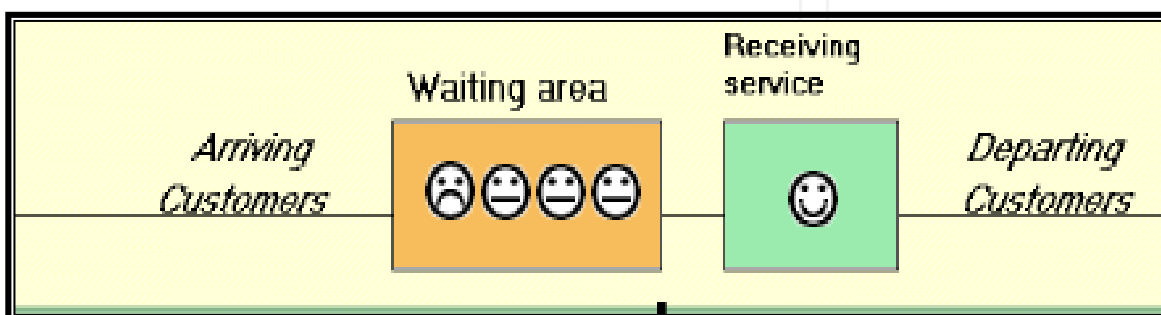


Fig. 2. A generic model of a service system

The following set of modeling considerations can help in simulating service systems:

- 1- Entities arrival to service system is random which can be considered a Poisson process. This does not apply to scheduled services such as doctor appointment and legal consultations. With the Poisson process assumption, entities inter-arrival time (t) is considered to be exponentially distributed with a Mean Time Between Arrival (MTBA) of $1/\lambda$ where λ is the arrival rate of entities (for example, customers per unit time). The number of entities who arrive within the specified time interval is a random variable that follows Poisson distribution with mean arrival rate of $\lambda = 1/\text{MTBA}$. In the simulation study, the entities' arrival process is observed and collected data (inter-arrival times) is used to estimate the distribution parameter (i.e., MTBA). Other standard and empirical probability distributions can be fit to collected data. However, based on experience, the random arrival of customers to many service systems such as banks, clinics, and restaurants follows the Poisson process is a good approximation. In some cases, certain limit can be put on the number of entities arriving to the system such as in paperwork processing and in orders made to copying centers.
- 2- Customer waiting time before reaching the service provider is collected from the model. Modeler needs to specify each queue's size and discipline. Model logic can be used to route customers, control their waiting pattern, and provide priority rules for processing. The size of waiting lines is determined based on facility features such as number of available seats, number of vehicles that can fit in drive-thru lane, and so on. With systems of limited capacity, the number of customers who left without service need to be recorded. In some cases, infinite system capacity can be assumed to focus the study on the performance of the service system.

- 3- Based on the nature of the service provided, service time is typically random. Data is collected on processing time using automatic or manual means. Since human-based services are mostly manual, motion and time studies can be used to record observations and estimate the service time considering human allowances. Observed service time can be approximated using standard probability distributions. In queuing system, an exponential distribution of service time with a Mean Service Time (MST) is assumed in order to apply the formulas of the queuing model. The service rate (μ) is then defined as $\mu = 1/\text{MST}$. In simulation, there is no need to be restricted to exponential distribution. The number of servers (s) and the service strategy highly impact the service and waiting times. The model logic can be used to implement service rules and the structure servers (serial or parallel, for example).
- 4- The flow of entities and customers between different types of services (if applicable) is implemented using the logical design of the business process in the modeled service system. Complex or simple decisions are often made during the flow of entities. For example, the process of applying for a loan at a mortgage company may include several steps before deciding to approve or decline the loan approved. Similarly, when a patient is admitted to a hospital, he/she may be exposed to different diagnostics before the doctor decides on the proper treatment of the patient.
- 5- The departure of customers or entities from the system may require some processing such as when a patient is released from a hospital or a clinic. Such rules also need to be considered in modeling the service system.

3.2 Model Elements

The structural components of a service system discrete-event simulation model typically include:

- Model entities: customers, requests, and orders.
- Model activities: Steps for processing customers and their orders/requests.
- Model resources: Service providers, labor, machines, etc.
- Model layout: Service departments, locations, areas, etc.

Other non-structural elements include model logic, a Random Number Generator (RNG), run controls, model data, variables (system state variables and global variables), statistics collectors, and a schedule/ a calendar. Once the components are known one could construct a model easily.

In general, elements of a service system model often include the following:

- 1- The structure of the service system including facility layout, departments, and locations of servers and waiting areas.
- 2- Entities/customer's arrival process. Empirical distribution or standard probability distribution can be used to model the arrival process.
- 3- One or more waiting lines in front of service providers. Queues size, discipline, and routing logic are modeled.
- 4- A service providing method that can be manual or automatic. Labor resources and/or automated operations can/ be used to model the service. Empirical distribution or standard probability distribution can be used to model the service time.

- 5- Logical design of flow between multiple servers along with decision-making process at decision points within the flow.
- 6- A departure process along with departure rules.
- 7- Statistics collections methods using counters, tallies, and customized code.

3.3 Model logic

Model logic controls the flow of entities through model activities, enforces the service rules and policies, and specifies the nature of services provided to customers. For example, the logic of a healthcare clinic model should capture the rules for classifying, scheduling, and admitting different types of patients. It also specifies policies such as overbooking, accepting walk-in patients, and cancellation. The logic also controls the flow of patients through clinic activities/departments from admission to release and specifies treatment rules, times, and resources.

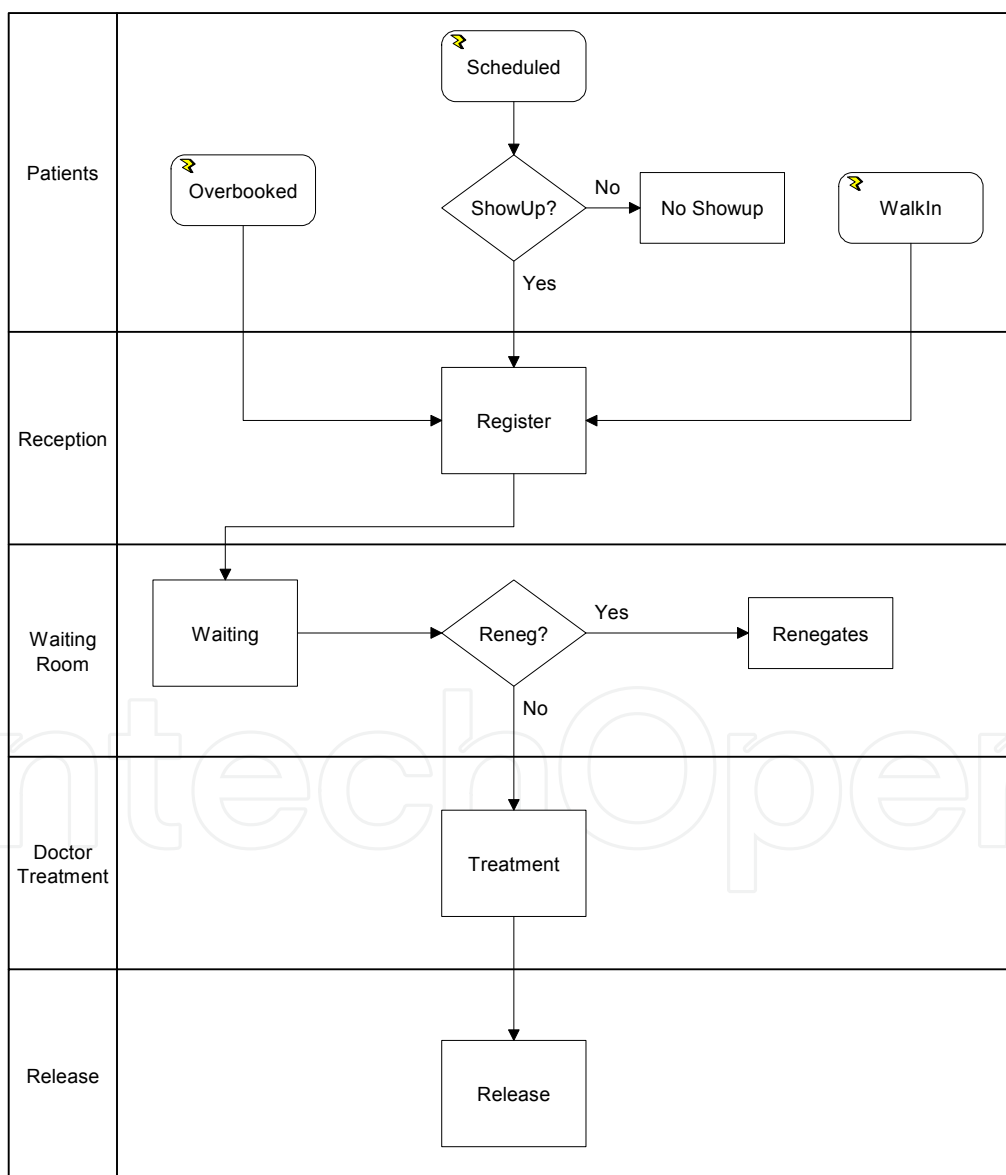


Fig. 3. An example of a healthcare clinic logic flow chart

Process maps, block diagrams, and flow charts are typically used to develop a conceptual model of the logic. Figure 3 shows an example flow chart that depicts the logic of a healthcare clinic model. The flow chart shows service phases (swim lanes), service inputs/outputs, start/finish, service sequence and flow, and decision points. Once ready, the flow chart is used to develop the clinic simulation model.

3.4 Model Data

Service systems such as banks, clinics, and restaurants require data on customer arrival, availability of resources, service times, size of waiting rooms, and so on. Examples of data requirements for a healthcare clinic simulation model can be, but not limited to:

- Patients schedule
- Patients admission and release time
- Size of waiting room
- Treatment time
- Allocation of nurses and doctors
- Operation time and reliability of X-Ray machines
- Clinic working hours

As discussed earlier, a key skill of model building is data collection where the analyst determines model data requirements and collects data. The following are proposed guidelines to properly determine model data requirements:

- Be clear on simulation objectives and deliverables.
- Understand the details of the service process.
- Specify the model measures of performance (KPIs)
- Develop a representative conceptual model
- Review similar/benchmark models
- Explore available data
- Be familiar with the specific requirements of the simulation software

3.4.1 Collecting inter-arrival and service times

Arrival and service rates are critical to model service systems such as banks, call centers, and restaurants. Arrival rates and service rates are essential to calculate system performance measures such as average waiting time, utilization, and average time in system. A simple table (Table 1) can be used to collect the arrival and service rates. For example, for customers arriving at a service center, the following form (showing the data for 20 customers only) can be used:

Customer number	Arrival time	Time since last arrival (TBA)	Service start time	Service end time	Service time (ST)
001	8:05	5 min	8:05	8:12	7 min
002	8:07	2 min	8:12	8:25	13 min
...					
020					
Sum	---	500 min	---	---	420 min

Table 1. A form for collecting inter-arrival and service times

For each customer, we record the times of arrival, service start, and service end (departure time). Using these times, we can calculate Time Between Arrivals (TBA) and service time (ST). The third and sixth columns are then averaged out to determine Mean Time Between Arrivals (MTBA) and Mean Service Time (MST), respectively. In this example, these values are calculated as follows:

$$\text{MTBA} = 500/20 = 25 \text{ min. and Arrival rate} = 2.40 \text{ customers/hr}$$

$$\text{MST} = 420/20 = 21 \text{ min. and Service rate} = 2.86 \text{ customer/min}$$

The entities arrivals can be modeled using distributions with mean values of MTBA and MST.

3.4.2 Collecting data for a call center

In cases where data collection is time consuming and costly, the data collection form should be designed to collect only relevant data at lowest cost and effort possible. For example, the “call time” is a key element when collecting data to model a customer service call center. Call centers typically receive calls for different purposes and at different times. These calls are answered by associates of different level of experience. For example, if a call center receives 4 types of calls (Complaint, Service, Payment, and Information). These calls are answered by operators of a 3-level experience ("A" less than three months, "B" three months to a year, and "C" more than one year) working three shifts (Morning, Afternoon, and Evening). This setup results in $4 \times 3 \times 3 = 36$ combinations. If a sample size of 10 is used at each combination, a total of 360 call times is collected. A simple form (Table 2) can be used for collecting calls time.

Call No.	Call Type	Call Time	Operator Level	Call duration (sec)
1	Complaint	AM	B	163
2	Service	PM	A	120
...	Payment	AM	B	215
360	Information	EV	C	55

Table 2. A form for collecting data for a call center

3.5 Model parameters and decision variables

Model control factors include the parameters that can be set and changed by the service system designer in order to enhance the system performance. In general the service system design is in control of the entities acceptance/admission to system, entities waiting and classification rules, the service providing process, the logic of entities flow between servers, and the rules of system departure. Entities arrival rate to the system is typically not within the control of system designers. Adjusting such processes may be translated into providing settings of key model control factors such as:

- 1- Percent or rate of admitted entities to the service system.
- 2- Capacity of waiting area or line.
- 3- Waiting discipline and rules of selecting customers to receive service. First Come First Served (FCFS) is the most common waiting discipline in service systems. A preemptive method can be also used to expedite or select customers to service.

- 4- Number of servers in the service system and their configuration.
- 5- Service time at each server.
- 6- Percentages used to route entities flow among servers.
- 7- Rules of system departure (if applicable).

Other model control factors include the set of decision variables that needs to be optimized in order to enhance the system performance. These include service prices, inventory levels, staffing level, and so on.

3.6 Model performance measures

A set of measures can be used to assess the performance of a service system as well as to compare performance of several system designs. Quantified performance measures should be used to assess the service system performance. Such measures can be estimated from model accumulated statistics or special code may be necessary to compute the measures values. Examples of services performance measures include:

- 1- Average waiting time per customer.
- 2- Number of customers left without receiving the service (in case no capacity or the waiting time was too long).
- 3- Time-in-system: The total time a customer spends in the service system (this includes waiting time, transfer time, and service time).
- 4- Average and maximum size of the queue (length of waiting line).
- 5- Servers utilization (percent idle and percent busy).
- 6- Service system throughput (number of processed entities per time unit such as number of served customers per day).
- 7- Service level (number of customers who finished the service without waiting or only with less than 5 minutes of waiting time).
- 8- Service cost
- 9- Percent of satisfied customers

4. Example of a Single-Server simulation

The single-server queues are, perhaps, the most commonly encountered queuing lines in service systems. Examples include business (e.g. sales clerk), industry (e.g. a production line), transport (e.g. a bus, a taxi rank, an intersection), telecommunications (e.g. Telephone line), computing (e.g. processor sharing). Even where there are multiple servers in the service system, it is possible to consider each server individually as part of the larger system (e.g. a supermarket checkout has several single-server queues that the customer can select from.) Consequently, being able to model and analyze a single-server queue is a particularly important in simulating service systems. Figure 4 shows a conceptual model of a single-server system with arrival rate (λ) and service rate (μ).

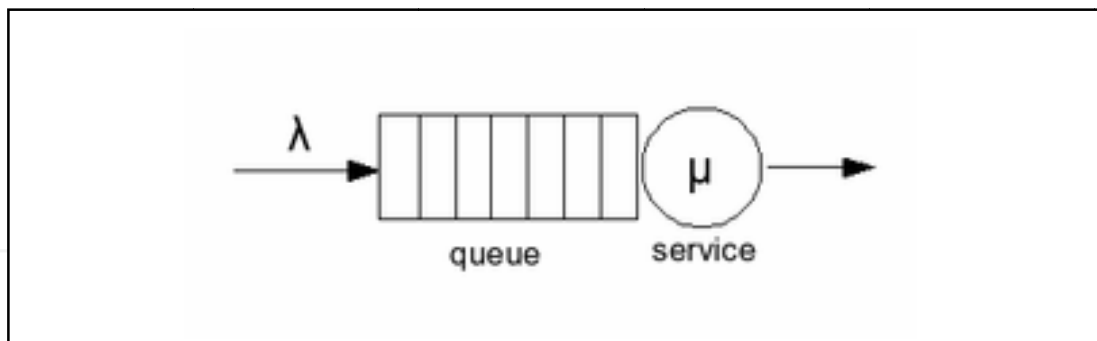


Fig. 4. A single-server model

As shown in Figure 5, the logic for a simple single server model can be presented using two flow charts; an arrival event and a departure event. The arrival event is executed based on the server status “busy or idle” and the departure event is executed based on the queue status “empty or full”.

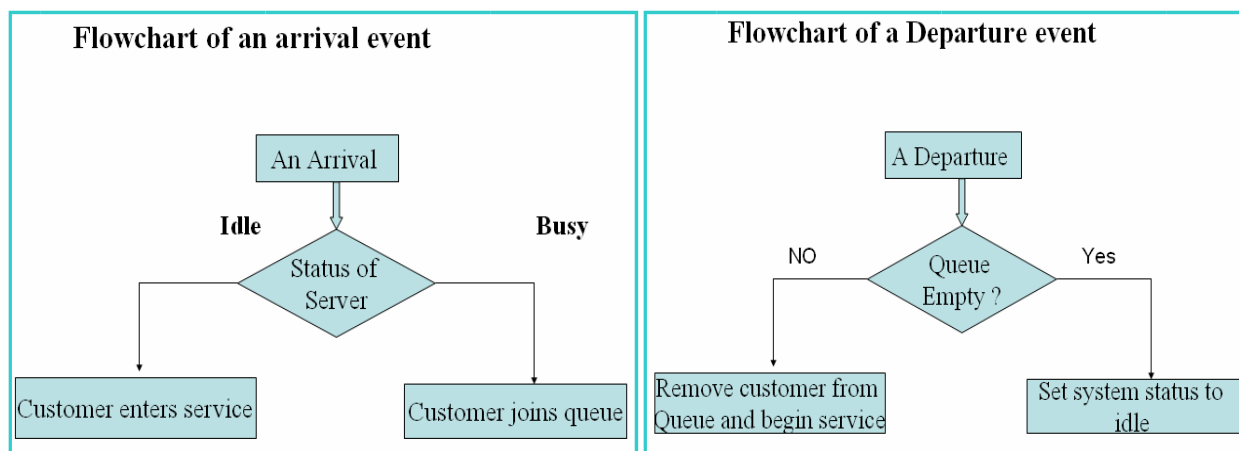


Fig. 5. The logic of a single-server model

Two data elements are required to model the single server; an arrival rate (λ) and a service rate (μ). To this end, the inter-arrival times and service times for 100 customers are collected. The mean inter-arrival time (MIAT) also known as Mean Time Between Arrivals (MTBA) for the 100 customers is found to be 3 minutes and the Mean Service Time (MST) is 2 minutes. Thus, the arrival rate (λ) and service rate (μ) are determined as follows:

$$\lambda = 1/\text{MIAT} = 1/3 \text{ customer/minute} = 20 \text{ customer/hr}$$

$$\mu = 1/\text{MST} = 1/2 \text{ customer/minute} = 30 \text{ customer/hr}$$

The simple single server simulation model can be then easily built based on the conceptual model in Figure 4, given the model logic in Figure 5, and using collected data (λ and μ values). In this example, ARENA™ simulation software is used to build the model. ARENA is one of the world's leading simulation software has been used successfully by organizations the world over to advance the efficiency and productivity of their business. Arena is designed to provide the power required for successful simulation within an easy-to-use modeling environment. With an animated Arena simulation model, we can design a new service facility or make changes to an existing one, and try different service scenarios

before we commit capital and resources. We can also compare operational strategies based on performance and confidently select the best one for implementation. Simulation results can be communicate to all parties concerned with the success of the project (from the management team who sign off on the decision, through to the general labor) and show all how the service system will function and specify the critical practical implications to consider in system implementation.

For our single-server model, the ARENA simulation model is show in Figure 6. As discussed earlier, the model comprises three main processes; an arrival process, a service process, and a departure process. The model is set to run for 8 hours per day as an example of terminating simulation.

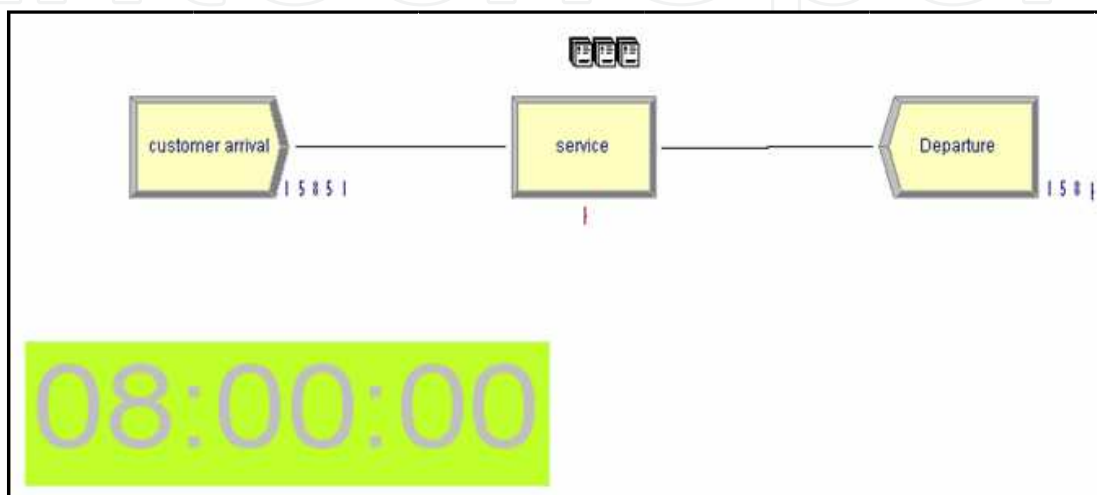


Fig. 6. Single Server Arena simulation model

Five KPIs are used to assess the performance of the single server model:

- Avg. waiting time (W_q)
- Avg. time in service system (W)
- Avg. number of customers in queue (L_q)
- Avg. number of customers in system (L)
- Server utilization (U)

Due to simplicity, these KPIs can be determined using queuing formulas. The single-server (M/M/1) queuing model formulas for the five KPIs are as follows:

$$L = \frac{\lambda}{\mu - \lambda} \qquad W = \frac{1}{\mu - \lambda},$$

$$L_q = \frac{\lambda^2}{\mu[\mu - \lambda]} \qquad W_q = \frac{\lambda}{\mu[\mu - \lambda]} \qquad U = \lambda/\mu$$

The following are the results of applying the queuing formulas to our single-server example:

- Avg. waiting time (W_q) = 0.067 hr = 4 minutes
 - Avg. time in system (W) = 0.010 hr = 6 minutes
 - Avg. number of customers in queue (L_q) = 1.333 customers
 - Avg. number of customers in system (L) = 2 customers
 - Server utilization (U) = 0.667

The simulation results for the 5 KPIs are as follows:

- Average waiting time in the queue = 4.07 min
- Average spent in service system = 6.08 min
- Avg. number of customers in queue = 1.28 customers
- Avg. number of customers in system = 2.02 customers
- Utilization = 0.66 or 66%

5. Simulation applications in Service Systems

Wide range of simulation applications can be used in service systems. These applications range from the design of new service facility to solving performance problems in existing service systems. Section 6 provides some case studies of applying simulation in modeling typical service systems. Some of those applications include. Examples of industry sectors that benefit from simulations studies in service systems include shipping companies, transportation, aviation, fast food, telecommunication, banking, and so on.

Planning the Service Facility

Simulation studies can be used to plan the facility of the service system. This includes designing the facility system, designing the layout of the service facility, and designing flow within the service facility. Different design alternatives can be evaluated using simulation based on the design implications on system performance.

Designing the Business Process

Modeling the business process in a service system includes modeling the way in which the service system receives orders, interacts with supplies, provides services, assures quality, receives payments from customers, and so on. Modeling the business process of service systems has become typically in the latest years especially with the applications of Business Process reengineering (BPR) methods.

Performance Improvement

Improving the performance of service systems is another key simulation application in this regard. Service systems may suffer from declining service levels, throughput, and utilizations of resources. They may also suffer from long waiting time and waiting lines and increasing loss in business opportunity. Simulation studies have been widely used to model the underlying system, analyze its performance, determining root causes of performance troubles, and propose solutions to the problems.

Decision Support

Because of the type of complex decisions that are often involved in business process of service systems, simulations studies are also used to act as a decision support system. Decision-makers can highly benefit from the model in making decisions. Model provides animation and statistics that can help decision makers draw inferences on model performance, compare alternatives, and select best-performing operating strategies.

Staffing and Scheduling

Since service systems are often operated by human, staffing human resource and scheduling their operating pattern is another simulation application in service systems. Examples include scheduling the work of nurses in hospital and deciding on best staffing level or chasing strategy. Staffing and scheduling is directly related to customer needs and demands.

Logistics and Supply Chain

Modeling the supply chain of a service system is also a typical simulation application. Supply Chain Management (SCM) in general includes scheduling supplies so that the service system needs are met and customer satisfaction is increased.

The following section presents three examples of simulating service systems. The objective is to show how our understanding of the nature of service system, the elements of service systems, and the service data and logic can be utilized in developing models that help in measuring performance, outlining problems, analyzing results, and improving performance.

5.1 Bank simulation example

The type of queuing system a business uses is an important factor in determining the business efficiency. This section presents an example of using simulation to assess the performance of a bank with multiple-channel queues. This type of queuing systems is commonly seen in banks and fast food restaurants. The bank model is used to simulate the queues and predict key statistics of queue length, waiting time, throughput, and time in system.

Main objectives of the bank simulation study include:

- Collecting data needed for building accurate model that is useful for taking improvement decisions.
- Using the model to analyze the behaviors of the existing system and predict its performance at various levels of input parameters (i.e., the arrival rate and service rate).
- Using the model to conduct "What-if" analysis and enhance performance

The bank receives customers and provides banking services between 8:00 AM – 5:00 PM five days a week. Each customer takes a numbered card upon arrival and waits for his/her number to be displayed on a digital screen. There are up to eleven servers in this bank (eight operate under normal conditions and three are utilized in peak times). Figure 7 shows the bank facility layout, the servers and service areas, and the queues at various types of banking services. As shown in Figure 7, the services provided to customer by the eight bank tellers in normal conditions are classified into four types:

- Service A: Cash (entrusting, checking, exchanging, etc.). Due to heavy demand for service A, 5 tellers are A-dedicated in normal conditions.
- Service B: Foreign currency (single server).
- Service C: Export exchanges (single server).
- Service D: Checkbooks and other services (single server).

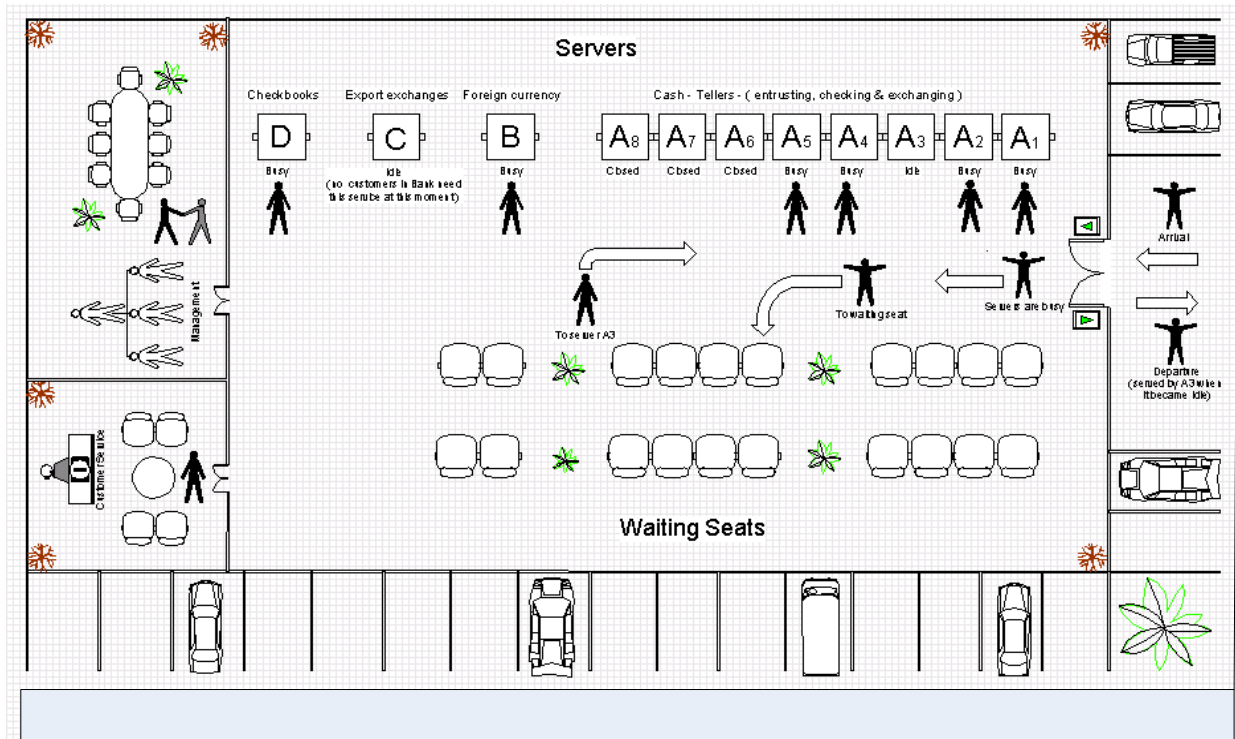


Fig. 7. Layout of the bank simulation example

The following assumptions are made in the development of the example DES bank model:

- Normal distribution of service time (the empirical data approximately satisfy the required conditions for this distribution).
- Exponential distribution of inter-arrival time (the empirical data approximately satisfy the required conditions for this distribution).
- No queue at the self-serve waiting card machine
- The model is focused on four customer stages: arriving, waiting at queue (if the required server is busy), receiving the service, and departure.
- No restriction on departure process or rerouting customers. Customers exit the bank immediately after completing their transactions.
- No warm-up period is used for the bank terminating simulation.
- Run time is 40 hours with 5 replications

The model data is collected and standard probability distributions are fitted to collected data. Table 3 shows the distributions and parameters used in the model in terms of MTBA and the parameters of the normal distributions of service times at each type of bank service.

Type	Exponential Arrival process	Normal Service process
Service A	MTBA =1.262 min	($\mu = 4.983$ min, $\sigma = 0.980$)
Service B	MTBA =11.190 min	($\mu = 4.857$ min, $\sigma = 0.970$)
Service C	MTBA =8.667 min	($\mu = 5.185$ min, $\sigma = 0.862$)
Service D	MTBA =18.000 min	($\mu = 5.308$ min, $\sigma = 0.910$)

Table 3. Standard distribution fitted to collected bank data

The following simulation elements are used in the example bank model:

- Entity: customers.
- Attribute: balance of customers checking accounts.
- Activity: making deposits or entrusting.
- State variables: number of busy servers, the number of customers being served or waiting in line.
- Exogenous event: the arrival of a customer.
- Endogenous event: completion of service of a customer.
- Queue: waiting lines or waiting seats.

Figure 8 summarizes the performance measures determined from the collected simulation statistics at each type of service provided by the bank example. The results indicate that most of customer demand is focused on service type A and an improvement plan is essential to be focused at service A in order to increase the number of served customers, reduce time in system, and increase customer satisfaction.

<p>Service A</p> <ul style="list-style-type: none"> ■ A total of 724 customers requested the service per day. ■ A total of 478 customers completed the service during the simulation. ■ The average time a customer spends to get the service is 16.04 min. ■ The average number of customers requesting the service is 120.94. ■ Average server utilization is 99.5% (4 servers)
<p>Service B</p> <ul style="list-style-type: none"> ■ A total of 48 customers requested the service per day. ■ A total of 48 customers completed the service during the simulation. ■ The average time a customer spends to get the service is 7.88 min. ■ The average number of customers requesting the service is 0.79. ■ Average server utilization is 47.6% (1 server)
<p>Service C</p> <ul style="list-style-type: none"> ■ A total of 58 customers requested the service per day. ■ A total of 57 customers completed the service during the simulation. ■ The average time a customer spends to get the service is 9.77 min. ■ The average number of customers requesting the service is 1.14. ■ Average server utilization is 61.2% (1 server)
<p>Service D</p> <ul style="list-style-type: none"> ■ A total of 27 customers requested the service per day. ■ A total of 27 customers completed the service during the simulation. ■ The average time a customer spends to get the service is 6.02 min. ■ The average number of customers requesting the service is 0.34. ■ Average server utilization is 29.3% (1 server)

Fig. 8. Summary of performance measure at different bank services

Model output analysis can highly benefit from the numerous statistics generated from simulation. Several scenarios and what-if-analysis can be tested and compared using the generated statistics.

6.2 Clinic simulation example

In this example, simulation is utilized to build a clinic model to assess proposed operational alternatives for maximizing the number of served patients while minimizing the patient’s time-in-system. The example describes how DES mechanics are utilized to represent clinic elements and patients’ flow and generate simulation data from relevant sampling distributions. A sample of model output analysis will be presented to demonstrate how the model provides answers to key questions relevant to clinic operation.

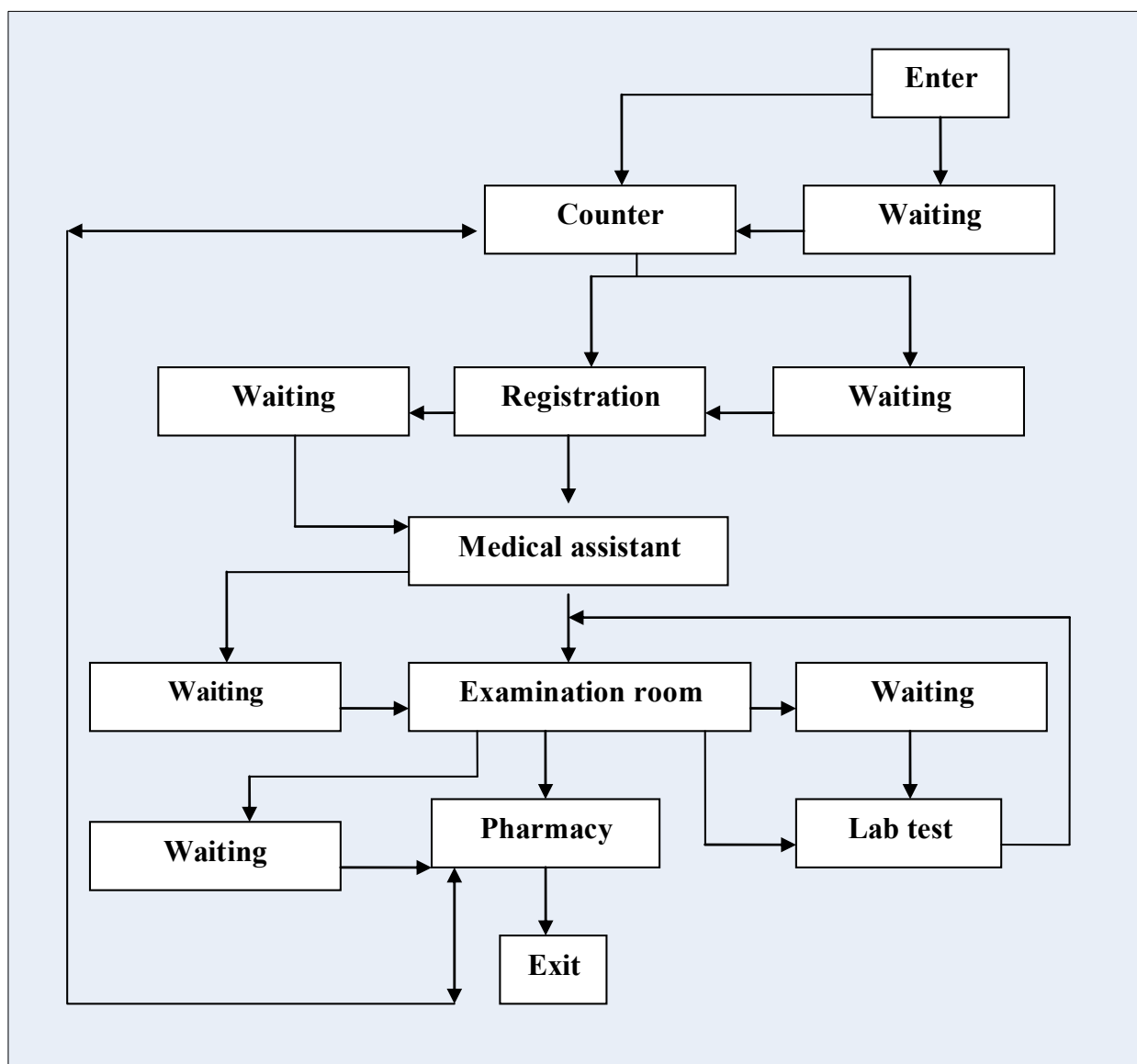


Fig. 9. A Process map of patients flow in the clinic example

The clinic consists of urgent care and acute care. Typically, most patients require acute care. Most of the urgent care patients are assessed by clinic doctors and sent to hospital. The clinic admits two types of patients; new patients (i.e. walk-ins) and returning patients (i.e. patients with appointments). Patients first arrive to the clinic's registration counter. If busy, they wait until its available, register, and wait for the medical assistant to admit them to the clinic. The medical assistant admits patients for initial checkup (blood pressure, temperature, etc.) and asks questions to assess each patient's case before they enter the examination room. The two physicians in the examination rooms diagnose patients, release them or direct them to lab test and pharmacy. If the patient is sent to the lab, he/she returns with lab results to the examination room to see the same doctor. Released patients leave the clinic through the registration counter.

Figure 9 shows a process map of the patients flow in the clinic. Patients' potential waiting points are also included in the process map. The process map represents a conceptual model that shows the clinic logic and patients' flow through a network of queues. The map also helped in collecting pertinent data at different elements in the clinic.

A WITNESS™ model is then built, verified, and validated. The model is developed to provide a set of performance metrics that characterize the clinic behavior at different scenarios of operation. The following assumptions are used in building the clinic simulation model:

- The patients' inter-arrival time is exponentially distributed with a mean of 15 minutes. Arriving patients register and wait to be called. Clinic waiting room has a maximum capacity of 50 seats.
- Clinic opens five days a week from 8:00 AM to 5:00 PM with one hour lunch from 12:00-1:00 PM.
- Based on clinic history, 25% of patients are required to take a lab blood test, which takes 25 minutes on average. Patients who take their lab test return to the same doctor who requested the lab test.
- 60% of patients are required to reschedule appointments with a clinic doctor for further treatment.
- 50% of patients are sent to the pharmacy to get prescription drugs.
- 15% of patients are treated by a clinic doctor and released from the clinic in their first visit.
- Clinic staff is distributed at clinic operations as shown in Table 4.

Resource	Staff
Counter	1 Clerk
Registration	2 Clerks
Medical care	2 Assistants
Examination	2 Doctors
Test lab	1 Technician
Pharmacy	1 Pharmacist

Table 4. Distribution of clinic staff

In order to model the variable times of clinic operations, standard distributions are fitted to collected simulation data. Table 5 summarizes the sampling distributions used in the clinic model.

Process	Patient type	Distribution
Arrival	All patients	Exponential (15 min)
Counter	Just entering clinic	Uniform (0.6,1.2) min
	To be released from clinic	Exponential (4 min)
Registration	New and walk-ins	Uniform (1.5,3.5) min
	Returning	Uniform (0.5,2.0) min
Medical assistant	Taking blood pressure	Normal (60, 5) sec
	Checking temperature	Normal (60, 5) sec
	Questionnaire	Triangular (2,4,10) min
Examination	All patients	Triangular (10,15,40) min
	Returning from lab test	Triangular (4,6,10) min
Lab test	Performing blood test	Normal (25, 3) min
pharmacy	First time	Triangular (1.6, 4, 8) min
	Returning	Triangular (1, 3, 5) min

Table 5. Sampling distributions in the clinic example

The clinic model involves a process for creating and directing the flow of two types of patients (Walk-Ins and Scheduled). Queues and Resources are then used to construct the clinic model. Syntax is written to direct patient flow and control the interactions among clinic operations.

Model Statistics and Confidence Interval:

The clinic model is an example of terminating simulation. The model is set to run 5 replications each of 5 days run length (8 hours/day) with no warm-up or initial conditions. Averages of the following clinic performance measures are generated from the model:

- Average time patients spend in the clinic = **84.62 min**
- Average treatment time (initial checkup and examination) = **56.1 min**
- Average waiting time (at all stages) = **28.52 min**
- Number of patients treated daily = **27 patients**

For each clinic performance measure, a set of descriptive statistics are also produced along with the half-width (*hw*) confidence intervals of 95% level of confidence. For example, if the waiting time in the clinic is a major concern to patients, the following statistics are collected:

Average	Std. Deviation	Min	Max	<i>hw</i>
28.52	3.81	14.50	42.00	±4.71

Model outputs indicate that the patient's waiting time can range from 14.5 min to 42.0 min with an average of 28.52 min. If we collect more samples and record the waiting time for the patients population, we can be 95% sure that the population mean is within 23.80 min to 33.34 min. This interval estimate can be more meaningful than the 28.52 min point estimate. For example, if the mean of the actual waiting time is turned to be 30 min, model results are still valid since this mean is within the established confidence interval.

Model Validation:

If records of these clinic performance measures are available, that data can be also used to statistically validate the simulation model. To this end, hypothesis testing can be used to test if the mean of any model-reported clinic performance measure matches that of the real-world historical mean. The collected sample of the 5 simulation replications can be used to reject or fail to reject the selected null hypothesis. For example, to test if the model produces a mean of 25 for the daily treated patients, the null hypothesis is set to $H_0: \mu = 25$ and the alternative hypothesis is set to $H_a: \mu \neq 25$. If we fail to reject the null hypothesis, then there is no enough evidence to believe that model is invalid. Similarly, if the actual mean waiting time is 30 min, $H_0: \mu = 30$ min, $H_a: \mu \neq 30$ min, $t_0 = -0.87$, and $t_{0.025, 4} = 2.77$. Since $|t_0| < t_{\alpha/2, n-1}$, we cannot reject the null hypothesis and we conclude that there is no sufficient evidence to believe that the model is invalid.

Comparing Simulation Scenarios:

Based on the model-reported results, the patient examination process was found to contribute to the major delay in the clinic. Examination process takes on average 42.90 min (i.e., waiting time of 20.97 minutes and treatment time of 21.93 minutes). The two clinic examination physicians are utilized as follows: 93.6% and 89.5%. This relatively high utilization explains why patients frequently complain of doctors pressured to complete treatment quickly.

The model is, therefore, used to reduce patients' waiting time and to increase treatment time without reducing the number of daily treated patients. To this end, a what-if scenario is suggested to remove one of the registration clerks due to reduced utilization and to add one examination physician due to the relatively high utilization. The analyst used the WITNESS Experiment module to set the two situations (scenarios) for the current (baseline scenario 1) and the proposed changes in clinic resources (scenario 2). Table 6 summarizes the results obtained from running the model experiments at the two scenarios of clinic operation. Results are expressed in terms of the four defined performance measures:

Performance measure	Scenario1	Scenario2
Average time in clinic	84.62 min	74.30
Average treatment time	56.10 min	60.12
Average waiting time	28.52 min	14.18
Number of daily patients	27	32

Table 6. Comparison of two clinic scenarios

It's clear from the results that Scenario 2 is better than Scenario 1 at all aspects. The proposed clinic changes have reduced the average of time spent in the clinic and increased treatment time. The reduction is mainly achieved in waiting time not in treatment time. This allows physicians to spend more time with patients without compromising the schedule. Increasing the physicians also allowed the clinic to admit more walk-in patients which resulted in increasing the total number of patients treated daily to an average of 32. The average utilization of the three physicians is reduced to an average of 75% (i.e., 74.8%, 75.5%, and 73.4%). The proposed clinic changes are validated with subject matter experts and recommended for implementation. Improvement was also justified with a cost-benefit analysis.

To compare scenarios based on waiting time, the following statistics are collected for waiting time at Scenario 2:

Average	Std. Deviation	Min	Max	<i>hw</i>
14.16	1.75	10.65	18.05	±2.17

It can be concluded from the results that Scenario 2 is better than Scenario 1 since it leads to lower average waiting time with less variability in terms of lower Std. Dev. and narrower confidence interval. Comparison analysis can be similarly conducted between the two scenarios at all clinic performance measures using the numeric and graphical descriptive statistics discussed earlier. To establish statistical evidence that Scenario 2 is superior compared to Scenario 1, we can test several hypothesis on the means and standard deviations of the four performance measures in Table 9.9. Using the procedure discussed earlier for the waiting time, null hypotheses can be set to indicate that means of waiting time at the two scenarios are equal ($H_0: \mu_1 = \mu_2$) and the alternative hypothesis to $H_0: \mu_1 > \mu_2$. The test statistic is $t_0 = 7.63$ and the critical value is $t_{0.05, 8} = 1.86$. Since $t_0 > t_{\alpha, v}$, we reject the null hypothesis and conclude that there is sufficient evidence to believe that Scenario 2 has less mean of waiting time.

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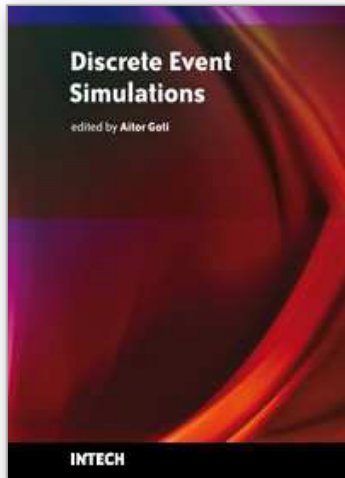
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Considered by many authors as a technique for modelling stochastic, dynamic and discretely evolving systems, this technique has gained widespread acceptance among the practitioners who want to represent and improve complex systems. Since DES is a technique applied in incredibly different areas, this book reflects many different points of view about DES, thus, all authors describe how it is understood and applied within their context of work, providing an extensive understanding of what DES is. It can be said that the name of the book itself reflects the plurality that these points of view represent. The book embraces a number of topics covering theory, methods and applications to a wide range of sectors and problem areas that have been categorised into five groups. As well as the previously explained variety of points of view concerning DES, there is one additional thing to remark about this book: its richness when talking about actual data or actual data based analysis. When most academic areas are lacking application cases, roughly the half part of the chapters included in this book deal with actual problems or at least are based on actual data. Thus, the editor firmly believes that this book will be interesting for both beginners and practitioners in the area of DES.

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