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Simulation Using Monte Carlo Technique Based on Queuing Theory of Bio-Clinical Laboratory

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Abstract:
The theory of Queuing models defined to avoid certain difficulties such as to minimize the waiting time of the customer, idle time of the system, etc. Monte Carlo Technique is one such method that provided an approximate workable solution to the queuing problems. The technique is based on computational algorithms that use repeated random sampling to arrive at numerical results. In this study, we are concerned with a bio-clinical laboratory which provides different tests. Thus operations research can effectively analyze such queues providing models relating to the practical situations.

Keywords: Monte Carlo technique, Probability distribution, Probability theory, Queuing theory, Service time, Simulation.

I. INTRODUCTION

In most service and production systems, the time required to provide the service or to complete the product is important and we may want to design and operate the system in such a manner to achieve the service standards. Generally, the time required includes the processing time and waiting time in the queue. Thus, Queuing theory is about the estimation of waiting times. It is concerned with the mathematical analysis of systems subjected to demands whose occurrences and lengths can be specified only probabilistically. A branch of applied probability theory is commonly known under various names as Queuing Theory or Traffic Theory. The term queuing theory is used to describe the mathematical theory of waiting for lines or queues, whereas a traffic theory is associated with the application of telephone and communication traffic and also vehicular traffics as they share a common ground. The basic quality of queuing model is that customers arrive randomly for service and get served based on the availability of a server. When the server has finished servicing previous customer, the successive customers can be served. Time between arrival of customer and start of service is called the *queue time* and customer departs the system after completion of the *service time*. Therefore, the *total time in the system* can be calculated by adding queue time and service time. Monte Carlo Simulation is a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making. It is a branch of "experimental mathematics" which uses random numbers to conduct experiments. A simulation is another word for imitating the actual process. In the Monte Carlo Simulation, we run through the various outcomes without actually going through a process or project. Typically the experiments are done on a computer using anywhere from hundreds to billions of random numbers. Monte Carlo simulations play an important role in computational science and engineering, with applications in all forms of material sciences.

II. HOW DOES IT WORK?

The Monte Carlo Simulation is a quantitative model that predicts each outcome and what the likelihood of each outcome is, where; the likelihood is termed as the probability in quantitative analysis. It performs risk analysis by building models of possible results by substituting a range of values—a probability distribution—for any factor that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions. Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is complete. Monte Carlo simulation produces distributions of possible outcome values.

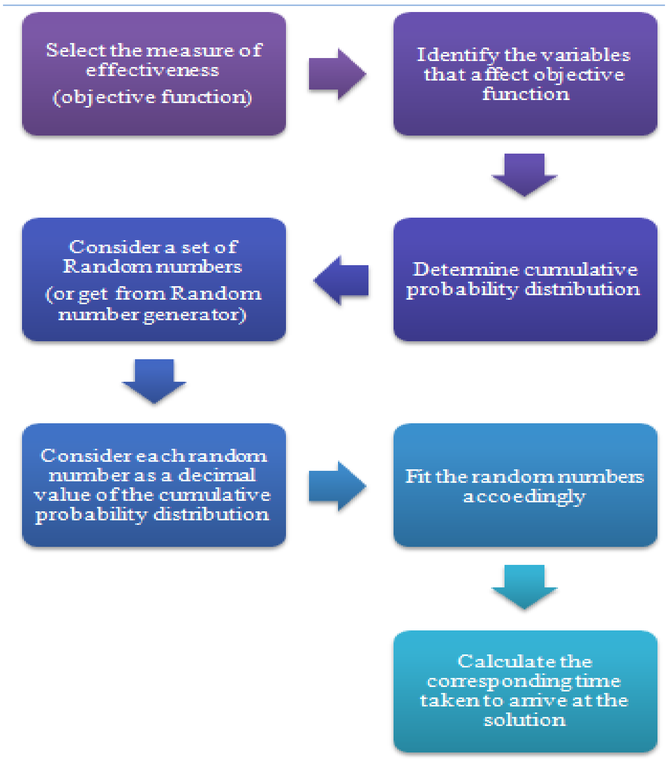

Figure I. Monte Carlo Simulation Methodology

By using probability distributions, variables can have different probabilities of different outcomes occurring. Probability distributions are a much more realistic way of describing uncertainty in variables of a risk analysis. Most commonly used probability distributions are:

- ***Normal Distribution*** with examples, inflation rates and energy prices

- ***Lognormal Distribution*** with examples, real-estate property values, stock prices and oil reserves.

- ***Uniform Distribution*** with examples, manufacturing costs or future sales revenues.

- ***Triangular Distribution*** with examples, past sales history per unit of time and inventory levels.

- ***PERT*** with example, duration of a task in a project management model.

- ***Discrete Distribution*** with examples, the results of a lawsuit: 20% chance of positive verdict, 30% change of negative verdict, 40% chance of settlement, and 10% chance of mistrial.

III. APPLICATIONS

Monte Carlo techniques are especially useful for simulating phenomena with significant uncertainty in inputs and systems with a large number of coupled degrees of freedom. Areas of application are:

- In physical sciences, it is used in designing heat shields and aerodynamic forms also in quantum chromo dynamics calculations.

- In statistical physics, it is used to compute statistical field theories of simple particle and polymer systems.

- In astrophysics, it is used to build models for both galaxy evolution and microwave radiation transmission.

- It is used to predict the net output of a wind farm during its lifetime providing different levels of uncertainty.

- In microelectronics engineering, to analyze correlated and uncorrelated variations in analog and digital integrated circuits.

- Used for planning wireless networks in telecommunications that mainly depends on number of users, their locations and service to be provided.

- In reliability engineering, it is used to compute system-level response for given component level response.

- It is used in engineering for sensitivity analysis and quantitative probability analysis in process design.
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- The repeated sampling of any given pixels in computational graphics can be used to evaluate correct solution of the given equation making it an accurate 3D graphics.

- Bayesian inference in phylogeny. Biological systems such as proteins membranes, images of cancer, are being studied by means of computer simulations which uses Monte Carlo methods.

- The local environment of molecule involving in some chemical reactions can be monitored under computer simulations.

- Monte Carlo method was helpful in developing a technique *'Monte Carlo tree'* which is useful in selecting the best move in a game.

- Monte Carlo approaches are an attractive option for turbulence simulations due to their capacity in both investigating systems with many degrees of freedom and their natural generation of a disordered velocity field structure and irregular particle trajectories.

IV. ILLUSTRATION

The example given understudies the arrival rate of patients to a bio-clinical laboratory and the problem is simulated using Monte Carlo simulation. Using this we can determine the average waiting time for each patient, the average idle time of the laboratory and the average service time for each test in a five-hour time period. The following (Table.1) provides the list of time required for various tests done in a bio-clinical laboratory.

Table.i. List of time required for various tests

TEST TYPES	TIME REQUIRED (MINUTES)	PROBABILITY OF TEST
BLOOD TEST	15	0.40
URINE TEST	15	0.20
BLOOD GLUCOSE LEVEL TEST	30	0.15
PREGNANCY TEST	30	0.20
VIRAL TEST	60	0.05

The Monte Carlo method is used for simulating the given problem. Considering the Random numbers to be,
10, 99, 65, 89, 95, 01, 79, 45, 16, 20, 49.

TABLE .II. MONTE CARLO SIMULATION

TEST	TIME	PROBABILITY	CUMULATIVE PROBABILITY	RANDOM NUMBER INTERVAL	RANDOM NUMBER FITTED
BLOOD TEST	15	0.40	0.40	00-39	10(1), 01(6), 16(9), 20(10)
URINE TEST	15	0.20	0.60	40-59	45(8), 49(11)
BLOOD GLUCOSE LEVEL TEST	30	0.15	0.75	60-74	65(3)
PREGNANCY TEST	30	0.20	0.95	75-94	89(4), 79(7)
VIRAL TEST	60	0.05	1.00	95-99	99(2), 95(5)

Thus the times taken by the bio clinical laboratory to treat the 11 patients in five-hour time period are, **15, 60, 30, 30, 60, 15, 30, 15, 15, 15 and 15 minutes** respectively.

TABLE. III.WAITING AND IDLE TIME TABULATION

PATIENT NO.	ARRIVAL TIME	CLINICAL TREATMENT STARTS	ENDS	WAITING TIME (minutes)	IDLE TIME OF LABORATORY (minutes)
1	7.00	7.00	7.15	-	-
2	7.30	7.30	8.30	-	15
3	8.00	8.30	9.00	30	-
4	8.30	9.00	9.30	30	-
5	9.00	9.30	10.30	30	-
6	9.30	10.30	10.45	60	-
7	10.00	10.45	11.15	45	-
8	10.30	11.15	11.30	45	-
9	11.00	11.30	11.45	30	-
10	11.30	11.45	12.00	15	-
11	12.00	12.00	12.15	-	-

IV(a) RESULTS AND INFERENCE:

Graphical solution:

a. Average waiting time of patients = 25.90 minutes.

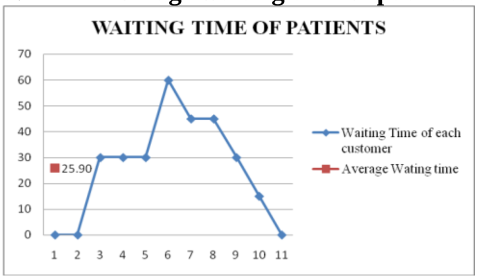

Figure.2. Average waiting time of patients

b. Average idle time of the laboratory = 1.36 minutes.

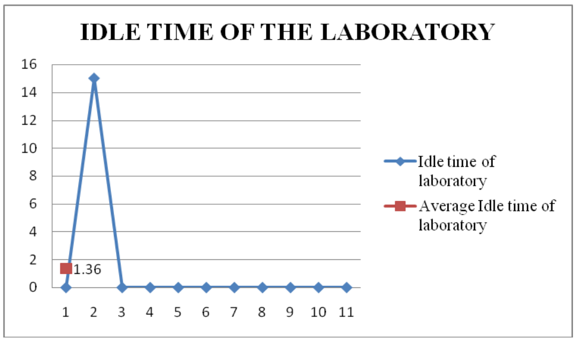

Figure. 3. Average idle time of laboratory

c. Average service time of the laboratory = 27.27 minutes.

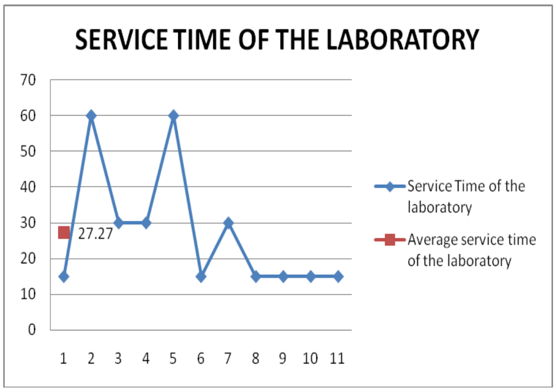

Figure .4. Average service time of laboratory

V. ADVANTAGES AND LIMITATIONS

Advantages:
Monte Carlo simulation provides a number of advantages over deterministic, or "single-point estimate" analysis:

- **Probabilistic Results.** Results show not only what could happen, but the probabilistic outcome of each problem.
- **Graphical Results.** It is easy and efficient to create graphical solutions to the problems with different outcomes and their chances of occurrence as the obtained data are clear and precise. This is important for communicating findings to other stakeholders.
- **Correlation of Inputs.** The factor of accuracy can be obtained. In Monte Carlo simulation, it's possible to model interdependent relationships between input variables.
- **Sensitivity Analysis.** With just a few cases, deterministic analysis makes it difficult to see which variables impact the outcome the most. In Monte Carlo simulation, it's easy to see which inputs had the biggest effect on bottom-line results.
- **Scenario Analysis.** In deterministic models, it's very difficult to model different combinations of values for different inputs to see the effects of truly different scenarios. Using Monte Carlo simulation, analysts can see exactly which inputs had which values together when certain outcomes occurred. This is invaluable for pursuing further analysis.

Limitations:

- Monte Carlo Simulation was originally developed to study properties of equilibrium system and it is not universally accepted as this method can also be used to simulate systems that are not in equilibrium.
- A single sample cannot be used to get the result of a simulation, instead, a large number of samples are to be obtained and the average of the sample is obtained as the result.
- Generating a large number of samples consumes much time to reach the desired results.
- Monte Carlo Simulation can provide only an approximation of true value and not the exact value.
- Construction of complex conditional probabilities is computationally intensive.

VI. CONCLUSION

Monte Carlo simulation is a flexible and powerful tool for social scientists working with statistical models. It is a broad class of computational algorithm that depends on repeated random sampling to obtain numerical results. The decisions could be categorized as very conservative, very radical, or in between. Monte Carlo Simulations are one such tool that is used to analyze risk and help us make better decisions. Thus they are used to reduce the risk involved with complex decisions where outcomes are uncertain. Both computer power and creative application of statistical theory have combined to make the simulation more feasible and more necessary for obtaining a better solution.

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