REPUBLIC OF TURKEY

ÇUKUROVA UNIVERSITY

INSTITUTE OF SOCIAL SCIENCES

DEPARTMENT OF BUSINESS ADMINISTRATION

SIMULATION IN MEDICAL SYSTEMS:
AN APPLICATION IN A HOSPITAL LABORATORY

Deniz YAMAN

MASTER'S THESIS

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Supervisor: Assoc. Prof. Dr. Selçuk ÇOLAK

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University of Çukurova, Institute of Social Sciences,

This study has been accepted as a MASTER'S THESIS in the department of Business Administration by the following jury members.

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APPROVAL

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ABSTRACT

SIMULATION IN MEDICAL SYSTEMS:
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Deniz YAMAN

Master's Thesis, Department of Business Administration
Supervisor: Assoc. Prof. Dr. Selçuk ÇOLAK
August 2013, 64 Pages

It has always been crucial to understand behavior and parameters of systems that determines the performance. Managing the mobility and complexity of both manufacturing and service organizations is a critical issue. In order to represent and evaluate those mobile and complex systems, developing a model is a reliable option. In this study, model of a hospital laboratory is developed by Arena simulation software. Hormone and biochemistry laboratories are included since other laboratories have structural differences and are processed separately. The model includes the processes after doctors' making order which are; arrival of orders, order acceptance, barcoding, blood-letting, pneumatic delivery, sample acceptance, processing test, evaluating results and result approval. During these processes of the laboratory, delays are observed in different stages which affect time of patients' getting test results and accordingly diagnosis time increases. For this reason, in this study queue waitings and delays in the laboratory are examined with the aim of minimization of total time spent in system and enhancing quality of service provided to patients. Within the scope of this study, simulation model is run for a time period of 90 day in order to reveal system related problems and probable solutions are suggested.

Keywords: Health Care Systems, Discrete Event Simulation, Simulation with Arena, Hospital Laboratories

ÖZET

SAĞLIK SİSTEMLERİNDE SİMULASYON:

BİR HASTANE LABORATUVARINDA UYGULAMA

Deniz YAMAN

Yüksek Lisans Tezi, İşletme Anabilim Dalı

Danışman: Doç. Dr. Selçuk ÇOLAK

Ağustos 2013, 64 Sayfa

Günümüzde sistemlerin performans ölçütü olan davranış ve değişkenleri anlamak çok büyük öneme sahiptir. Hem üretim hem servis işletmelerindeki değişkenliği ve karmaşıklığı yönetebilmek kritik bir husustur. Bu gibi değişken ve karmaşık sistemlerin temsil edilebilmesi ve değerlendirilebilmesi için model kurmak güvenilir bir seçenektir. Bu çalışmada, bir hastane laboratuvarı Arena simulasyon yazılım programı kullanılarak simule edilmeye çalışılmıştır. Diğer laboratuvarlar yapısal farklılıklara sahip olduğundan ve ayrı süreçler içerdiğinden, bu çalışmaya hormon ve biyokimya laboratuvarları dahil edilmiştir. Model, doktorun istem yapmasından sonraki aşamaları içermektedir. Bu süreçler; istem gelişleri, istem kabul, barkodlama, kan alma, pnömatik transfer, numune kabul, test analizi, sonuçların değerlendirilmesi ve sonuç onay işlemleridir. Bu süreçler esnasında bazı evrelerde gecikmeler gözlenmiştir. Bu gecikmeler hastaların sonuç alma süresini artırmakta, dolayısıyla doktorların teşhis koyma zamanını geciktirmektedir. Bu çalışmada, laboratuvardaki kuyruk beklemeleri ve gecikmeler, hastaların sistemde kalma süresini minimize etmek ve hastalara sunulan hizmet kalitesini artırmak amacıyla analiz edilmiştir. Bu çalışma kapsamında sistemsel problemlerin ortaya çıkarılabilmesi amacıyla simulasyon modeli 90 günlük bir zaman dilimi çalıştırılmış olup muhtemel çözümler önerilmiştir.

<u>Anahtar Kelimeler:</u> Sağlık Sistemleri, Kesikli Olay Simulasyonu, Arena Simulasyonu, Hastane Laboratuvarları

ACKNOWLEDGEMENTS

I would like to thank Associate Prof. Dr. Selçuk Çolak, chair of my thesis committee and my advisor. I'm also grateful to my committee members; Associate Prof. Dr. Arzu Uzun and Assistant Prof. Dr. Hüseyin Güler. I appreciate Research Assistant Yusuf Kuvvetli for his contributions. I would also thank managers and personnel of the hospital core laboratory, who gave me the chance to make this study.

A bunch of gratitude is to my family who emphasizes the importance of standing on one's own feet and education is the most valuable asset in life. Lastly, my dearest friends who are with me not only during happinesses but also in hard times; I'm glad they are in my life.

This study is supported by Scientific Research Projects of Çukurova University with the project number of İİBF2013YL5.

Deniz YAMAN

August, 2013, Adana

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LIST OF ABBREVIATIONS

BC: Biochemistry

BLS: Biochemistry Laboratory Services

DES: Discrete Event Simulation

HC: Health Care

HIMS: Hospital Information Management System

HSQS: Hospital Service Quality Standards

SD: System Dynamics

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CHAPTER I

INTRODUCTION

Simulation is a strong and practical decision making tool for service and manufacturing systems in order to increase the efficiency and provide improvements within the systems. Importance of the study, research scope and objective, and research design is expressed in this chapter.

1.1. Importance of the Study

Simulation provides opportunities to the businesses and gives the chance of observing what-if situations of the systems like the running of the processes and analyzing the potential results of changing some or whole parts of the system without actually making any modification. If a business has an outdated technology, needs to be renewed to pursue competitive advantage against its rivals and has more than one options to implement, simulation is a strong choice to make use of since it requires less time and costs than actualizing the change.

Before widely usage of computer simulation, practitioners had difficulty in analyzing complex systems due to the high analytical requirements; only mathematicians or operation research analysts were able to study on the high complexity level topics. Development of the simulation methodologies and the specific software packages let the practitioners study the systems dynamically in real time instead of analyzing statically at a given point of time. Also programming requirements and complicated background calculations are not necessary anymore in order to use simulation as an analysis method.

As the consciousness of the society grows up, the significance attributed to Health Care (HC) also increases. This results in such a situation that people become very selective when choosing the medical institution. It becomes harder day by day to satisfy patients in all aspects, since the patient profile is more interrogator and aware of their rights than the past. The medical institutions such as hospitals or medical laboratories are obliged to have a professional management process and a strong infrastructure. HC providers need to find ways to work with a higher level of operational efficiency while supplying a high level of quality at reasonable cost rate.

1.2. Research Scope and Objective

During processes of the hospital laboratory that is investigated in this study, delays are observed in different stages. These delays lengthen the time patients wait for their test results and diagnosis of the patients' illnesses retard accordingly. Waiting queues can be visually observed if related departments are visited. In this study, hormone and biochemistry departments of hospital laboratory are included since other laboratories differ from each other due to structural issues. System's probable problems are aimed to be investigated in a period of 90 day. Despite the fact that the analysis duration mainly depends on automation system, other processes also affect the time that tests are resulted. In order to comprehend the parameters and behavior of the system which are closely related with the performance, a simulation model is considered as a proper and credible tool. The results of the simulation model are expected to reveal offers that will enhance the quality of service and shorten the total time spent in the system.

1.3. Research Design

The framework of this research is proceeded in the course of following short summary: In *Chapter I* importance of the study, research scope and objective are expressed. In *Chapter II* simulation is defined, many aspects of simulation are mentioned, the concepts related to simulation and real life applications are briefly explained. Also, general applications in medical systems and a sectoral frame are discussed. Lastly, the basic concepts of queuing are portrayed. After this part, in *Chapter III* simulation applications in medical systems are examined. Firstly, an overall literature review is given and then, previous relevant studies in HC providers are presented individually. In *Chapter IV*, material and method are explained. In the material part the hospital laboratory, data collection, problem description, problem assumptions, work flows are illustrated in detail; while in the method part the steps of simulation, arena model and output analysis are introduced. In *Chapter V* data analysis, the results deduced from the simulation analysis, recommendations and conclusion take place. Limitation of the study and future studies are also expressed in last chapter.

CHAPTER II

SIMULATION, MEDICAL SYSTEMS AND QUEUING

In this chapter, simulation is described in detail, medical systems are mentioned, and queuing is introduced.

2.1. Simulation

Simulation heading will be investigated under sub headings of General Information About Simulation, Importance of Simulation, The Concepts Related to Simulation and Real Life Applications.

2.1.1. General Information About Simulation

Simulation is trying to duplicate the design, characteristics and features of an existing system. In order to form a model of a real life system, instruments like mathematical models or computers are needed. The logic behind simulation is; it lets see the system as a whole, estimate the experimental results and effects of various actions without actually doing them. Simulating any system is possible as long as it can be formulated quantitatively. The aim is to predict the future scenarios, to observe how the system will respond and to find the best alternative according to the system objective. There are many tools like computer programs and softwares for simulating systems (Render, Stair and Balakrishnan, 2003, p. 409).

Simulation can be defined as imitating systems which include types of real world facilities or processes. In order to base the study on a scientific framework, assumptions should be made in accord with the system features. The assumptions are often expressed by mathematical and logical relationships, hereby a model, which reflects the behaviors of the existing system, is formed (Law and Kelton, 2000, p. 1).

In the process of simulation, an existing physical system is being formed through a computer based mathematical model and potential outcomes are being experienced. The term ‘system’ stands for the entire structure which has a prescribed aim and contains the transformation phase of inputs to outputs (Chung, 2004, p. 2).

Simulation enables companies to see the outcomes of what-if questions related to the possible changes within their processes without actually carrying out system alterations. Regarding the clarity of the input quantities, a simulation model embodies uncertainty in at least one input quantity. When a simulation is run, those input quantities take on random values and the resulting output quantities are examined. The relationship between inputs and outputs gives track about how the outputs change due to the variations in the input values (Winston and Albright, 2001, p. 564).

According to Altıok and Melamed, simulation modeling generates simplified representation of complex systems that are studied on. The goal of the experimentation is defined in anticipation such as; enhanced process design, cost-benefit analysis, and sensitivity to system parameters. The modeling process includes collecting the system history, which is composed of observation data and statistics through time, symbolizes the system behavior. While one significant part of the simulation is the system behavior, the other part is the system structure represented by the model created, reflecting the structural features of the system (Altıok and Melamed, 2007, p. 1).

2.1.2. Importance of Simulation

Harrel and Tumay (1995) liken the benefit of simulation to the experience gained by a pilot from a flight simulator in which there is no risk about nothing. Pilot has a right to make mistakes in the simulated environment, does not consider time and cost issues, eliminates those mistakes and gives better performance in actual flight. Simulation in production and service systems provides cognition of the system operations and competency to make timely and intelligent decisions, just like the flight simulation.

Banks and Gibson (1997) expresses that simulation is such a strong tool that in some sectors it is called a universal solution. Simulation is widely used for numerous different cases due to its reputation and the availability of software packages, however all of them do not conclude successfully. The reason for this kind of failures is just the misapplication. It is very significant to determine whether simulation is the appropriate tool for the existing problem to be solved, or not. Banks and Gibson (1997) assert ten rules about the cases in which applying simulation is not proper and recommend not simulating when: common sense analysis works for the problem; a closed form or analytical methods can solve the problem; realizing direct experiments requires less effort; the cost of simulation is more than the anticipated gaining; proper resources for the project are not accessible; the time is too limited to interpret the results; data or even estimates are lacking; verification or validation is not possible; project expectations cannot be met and the behavior of the system is too complex to be defined.

Since simulation is a computer based application, it saves long periods of time when the results of specific process changes are intended to be examined, namely experimentation can be completed in compressed time. If the relevant changes are tended to be actualized in practice, it would last months or even years to complete. That is; simulation enables to evaluate a system with a long frame in a shortened period of time. The opposite situation would cause high amounts of costs related to both time and money. Since the running time of simulation is far less than the real life operations, it is possible to repeat and increase the reliability of the analysis statistically (Chung, 2004, p. 4). In case of practicing properly, simulation can provide flexibility in terms of adapting many alterations with ease to the case scenarios. Different policy possibilities can be tried out and many what-if questions can be satisfied by means of simulation in such short time like minutes. This feature is especially useful when adopting new system designs (Render, et al., 2003, p. 410).

Improvements in the domain of simulation provide the model operation animating dynamically and this increases the model credibility. The models can easily be demonstrated, otherwise it would not be possible to show the behavior of the system and how the model handles different situations (Chung, 2004, p. 4). When studying on an extensive and complicated real life case, it may not be possible and logical to use conventional decision making models. If the system, which would be analyzed, is an example of a hospital, a city government system, educational system or food system; mathematical models are incapable of successfully modeling (Render, et al., 2003, p. 410).

By means of simulation different policies, organizational procedures, decision rules can be tried out and evaluated without altering the existing operations of the ongoing systems. According to the results of the trials new designs or layouts can be experimented and this can be implemented without lacking any physical resources. While running the simulation, the interaction among variables and the significance of the variables to the extent that their influence on the performance of the system can be driven and perceptions are possible to be obtained (Banks, et al, 2010, p. 6).

2.1.3. The Concepts Related to Simulation

A *system*, according to Schmidt and Taylor (1970), can be defined as a collection of entities such as; people, machines (m/c) and components that interactively work together for the aim of reaching a logical end. The *state* of a system is composed of variables which represent the characteristics of the system in a specific time and those characteristics should be certainly in accordance with the nature of the study.

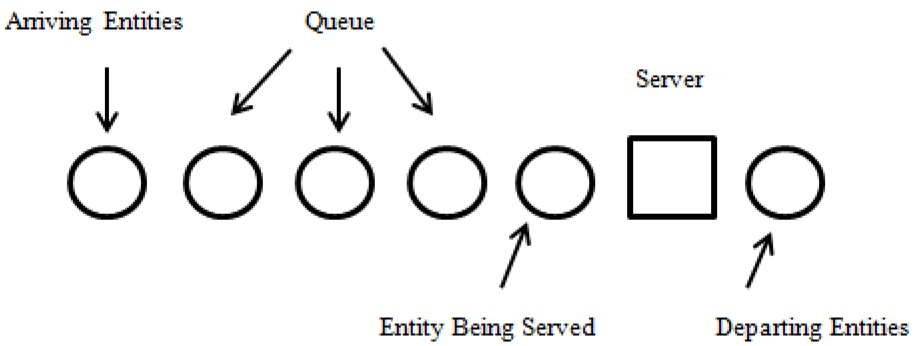

Figure 1. Basic simulation model components

Source: Chung, C.C. (2004) *Simulation Modeling Handbook.* USA, CRC Press.

Each and every system consists of three types of major components which are; entities, queues and resources. The relationship among those components is shown in Figure 1. *Entities* are the players which change the status, affect and also affected by other components. They can be people, objects or m/c's depending on the structure of the system. Second major component of the systems is *queue*s which represents the lines waiting for their turn to be processed. The queue characteristics will be examined in detail at part 1.3. The third component of a system is *resources* that serve or process the entities waiting in the queues. The resources may be idle or busy due to the crowd of the entities. In the case of a complex model, resources may be failed or inactive. The reason of failed resources can be inoperative equipment or broken m/c's. Inactive resources can exist because of meals, vacations, predetermined work breaks or maintenance times (Chung, 2004, p.10).

In addition to the three components aforementioned, three more concepts can be described as pieces of a system to be simulated which are; attribute, variable and event. *Attribute* can be defined as a common characteristic that all entities own, but in different values such as; due dates, priorities or colors. *Variables* give information about the system and can be separated into two groups; arena built-in and user-defined variables. The examples of number of busy machines, number in queue, current simulation clock time can be given for arena built-in variables; whereas travel time, current shift or mean service time can be given for user-defined variables. Variables are related with the whole system, however attributes can be thought as tags attached to entities. *Event* is an action happens in an instant of time that affects the system; the attributes or variables (Kelton, Sadowski and Sturrock, 2007, p.21).

Systems are categorized in two types; discrete and continuous. In a *discrete system* state variables can change rapidly at particular points in time. For example in a bank branch, customers come and go, then the number of the customers in the branch changes. However in a *continuous system* state variables change with respect to time and this change is continuous. An airplane flying in the air is an example of a continuous system because the state variables like the position in the air and the velocity changes due to time, not anything else. Although in real life, few systems are purely discrete or continuous, most of the systems are called as the overriding one (Law and Kelton, 2000, p.3).

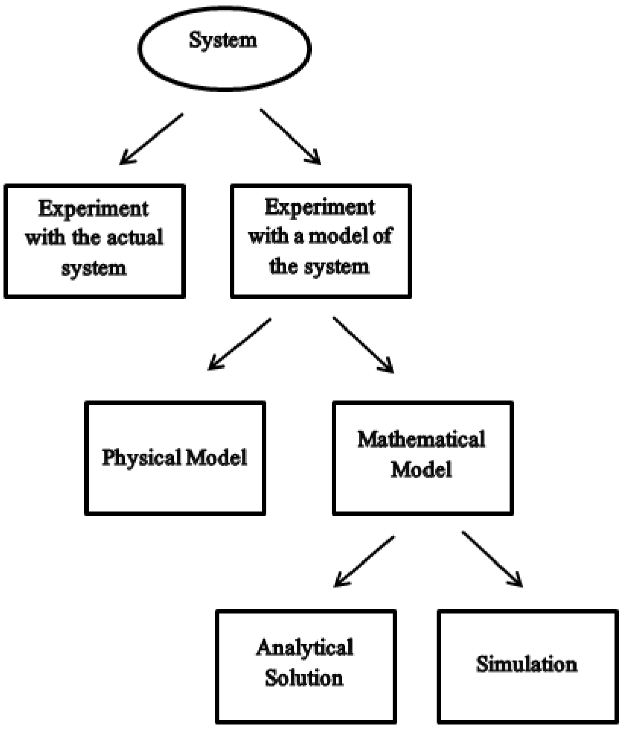

Figure 2. Ways to study a system

Source: Law, A.M. (2007). *Simulation Modeling and Analysis* (4th ed.). McGraw Hill, New York.

In Figure 2 the ways of studying a system is shown. The first junction is to choose experimenting with the actual system or a model. If the experimenting with the actual system is feasible and cost effective, doing so would be logical because there would be no doubt about the validation of the study. However studying on the actual system does not provide efficiency in most of the real life cases. Models have two types at the first step; physical and mathematical models. Physical models are not used generally for management or engineering systems. Mathematical models represent systems with the help of quantitative and logical relationships which provide cognizance of the system responses to changes. At this point, the model's validity is crucial because it shows the degree of model's representing the real system. If the model is simple enough to be represented by relationships and quantities, besides if the mathematical model is suitable for an analytical solution, for certain it is preferred. However, many of the models do not have that simplicity; those highly complex kinds of models should be studied by simulation.

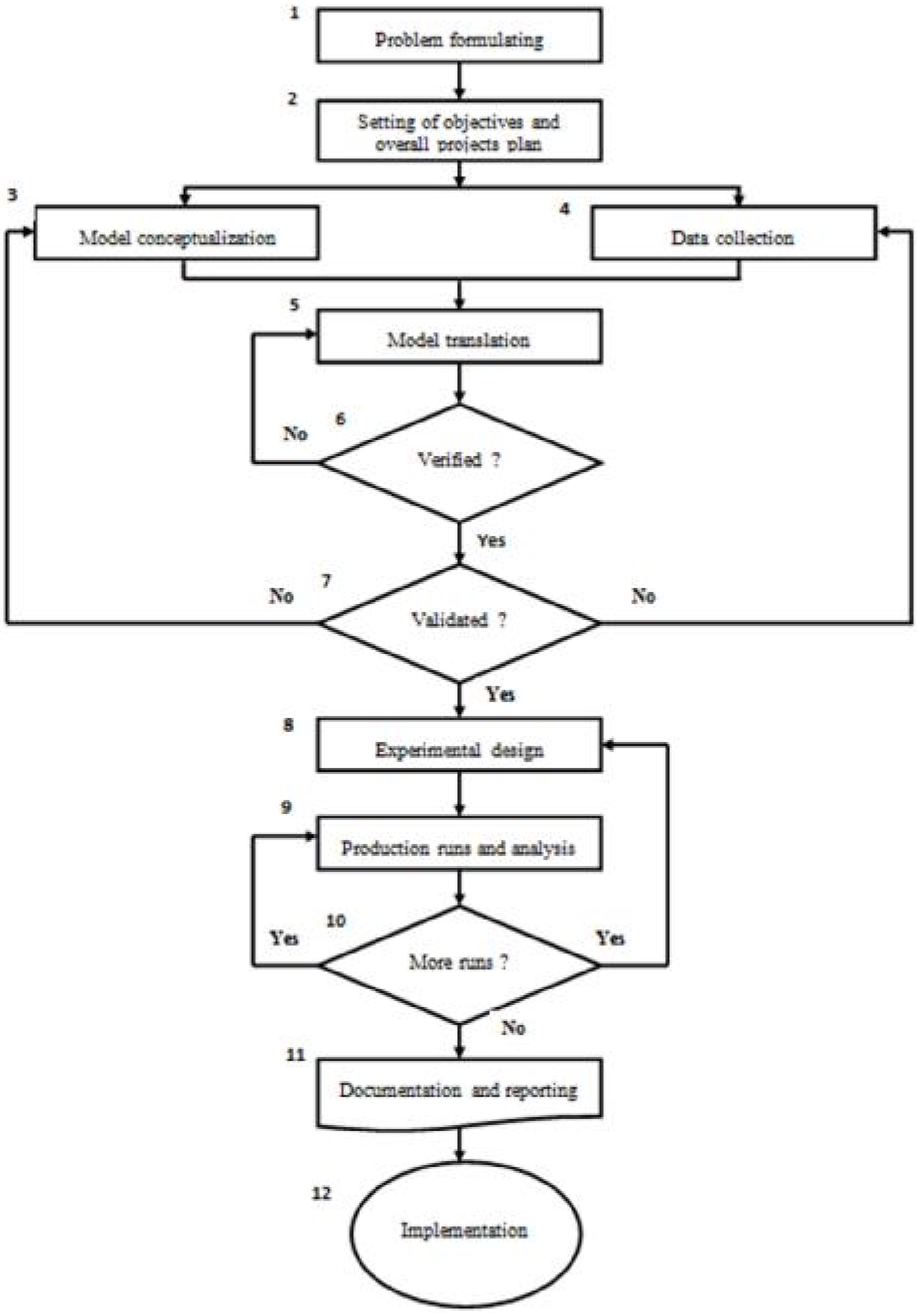

Figure 3. Steps in a simulation study

Source: Banks et al, (2010). *Discrete Event Simulation* (5^{th} ed.). Prentice Hall.

The steps in a simulation study are illustrated in Figure 3. It begins with problem formulating; objectives and overall project plan are set and then model is conceptualized, data is collected. After model translation, model should be verified and validated. According to Zeigler, et al, (2000) verification checks if a simulator is in error whereas, validation checks if a model is in error (p.367). If verification is not provided, model translation is checked. After verification is completed, validation comes up next. If the model cannot be validated, model conceptualization and data collection stages are repeated. After validation experimental design, production runs and analysis are done. In case of requirement of more runs, experimental design process is repeated. Documentation and reporting is done and eventually recommendations are implemented according to the simulation results.

There exist two simulation types depending on the system variable characteristics; these are *Discrete Event Simulation* (DES) and *Continuous Simulation*. DES is proper for problems including variables that change in discrete times; whereas continuous simulation can be used within the systems in which variables can change continuously. Within this study, DES will be conducted. According to Özgün and Barlas (2009) DES aims finding statistical estimates for equilibrium values of output variables and dynamic behaviors are not significant that much. Figure 4 is an example of discrete system state variable which is number of customers waiting in the line or being served in this particular case.

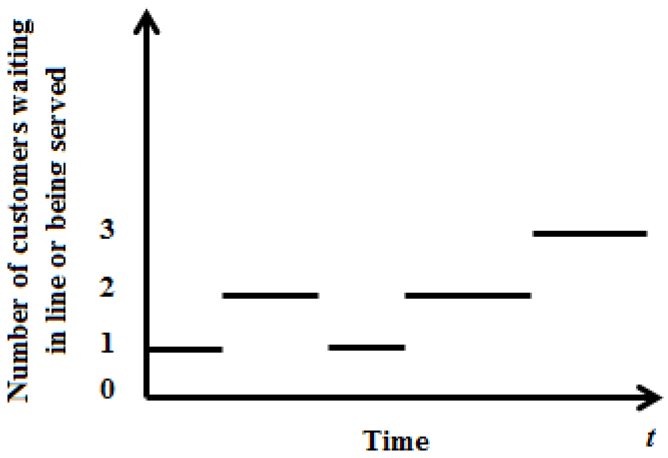

Figure 4. Discrete-system state variable

Source: Banks, et al, (2010). *Discrete Event Simulation* (5^{th} ed.). Prentice Hall.

Figure 5 is an example of continuous system state variable which is head of water behind the dam in this particular case.

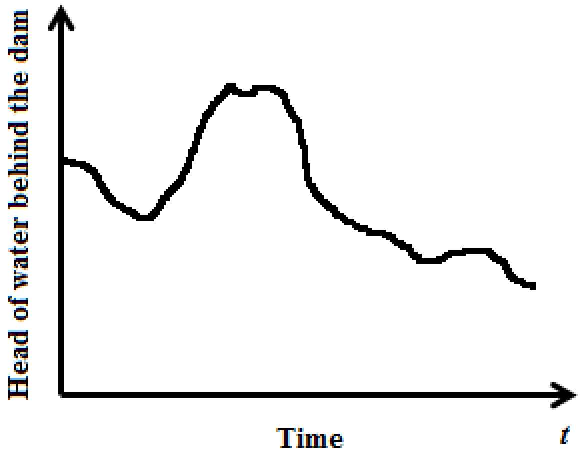

Figure 5. Continuous-system state variable

Source: Banks, et al, (2010). *Discrete Event Simulation* (5th ed.). Prentice Hall.

2.1.4. Real Life Applications of Simulation

Companies use simulation as a multi-directional tool in order to make decisions, which serve the predetermined specific goals, related to their processes. Regardless of the sector, simulation is preferred because it is cost-effective than actually carrying out the system changes. The aim of using simulation would also be risk analysis, which provides to choose one among several investment alternatives (Winston and Albright, 2001, p. 564). The application areas can be collected under the headings of manufacturing applications, water fabrication, business processing, construction engineering and project management, logistics, transportation and distribution, military applications, HC, and additional applications. (Banks, Carson, Nelson and Nicol, 2010, p.7).

Application areas of simulation are versatile and simulation is used for solving problems from different types of areas. Some of the application areas can be listed as designing production systems; comparing designs for service organizations like call centers, hospitals, banks; reengineering management processes; evaluating financial or economic systems (Law and Kelton, 2000, p. 2). According to Altıok and Melamed (2007), application areas of simulation modeling can be classified as manufacturing systems such as production lines, inventory systems, job shops, flow shops; supply chains; computer and communication systems such as client server systems, communication networks;

transportation systems such as seaports, airports; theoretical topics and also practical ones (Altıok and Melamed, 2007, p. 1).

2.2. Medical Systems

In this section, information will be given about medical systems in general, medical laboratories, medical laboratory developments particularly in Turkey and standards for biochemistry laboratory service.

2.2.1. Medical Laboratories

The laboratories can be regarded as a critical component of self-care, patient care, public health and biomedical research. An estimation of 70 percent of medical decisions related to prevention, diagnosis and treatment involve lab tests (Ihealth reports, 2009). According to Froehlich and Welch (1996) approximately 62 percent of the patients expect to receive a test during the physician visits and this corresponds to the 63 percent of the patients who expect to receive drug prescription.

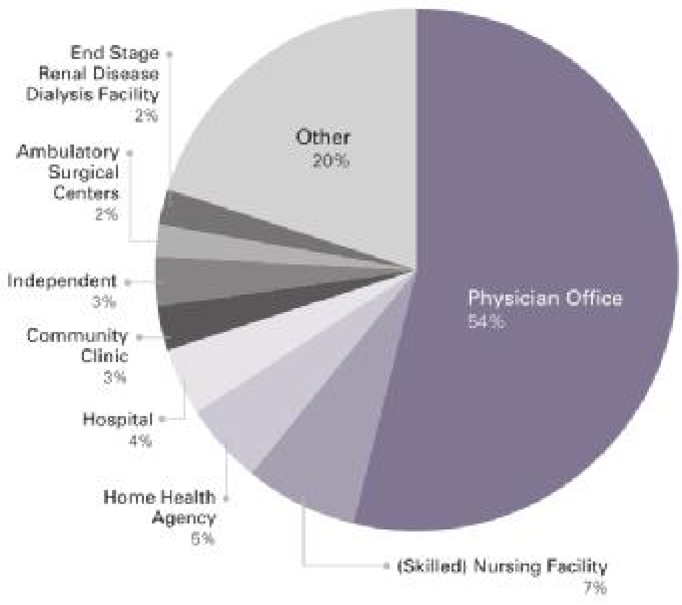

Figure 6. Most common types of labs

Source: Centers for Medicare & Medicaid Services. 2007. *Clinical Laboratory Improvement Amendments Update.*

As it is seen in Figure 6 physician offices, hospitals, nursing homes, public health departments, independent labs and other facilities do lab testing. Hospital labs constitute only 4.4 percent of the entire market; however in 2006 according to Ihealth reports (2009) they had the 55 percent of all and performed the largest share of testing regarding the volume and the revenue. Ihealth reports (2009) also assert that regulatory, economic and workforce factors shape the dynamics of the lab sector in terms of regulatory safeguards, competitiveness and future workforce demands. For example the efforts to decrease costs create pressure.

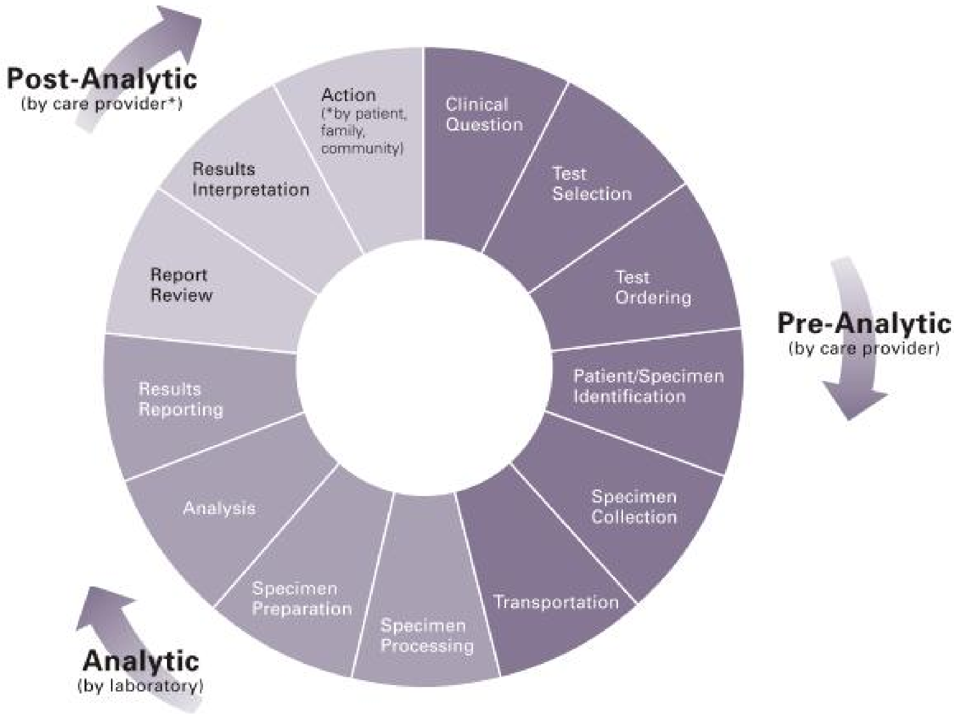

Figure 7. Total testing process

Source: Boone, J. (2007). Presentation at the Institute on Critical Issues in Health Laboratory Practice: Managing for Better Health, Atlanta.

Figure 7 shows the steps taking place in the total testing process which are pre-analytic, analytic and post-analytic. Pre-analytic processes practices begin with clinical question, test selection, test ordering, patient/specimen identification, specimen collection and transportation. Analytic processes include specimen processing, specimen preparation, analysis and result reporting. Post-analytic processes are report viewing, result interpretation and the action taken by the patient, family or the community. As it is seen in the figure there are many jobs which are interrelated with each other and should be carried out one after another. Actually, the system has a high level of complexity and many affecting factors as a whole. In each step, related data should be kept and generally is recorded.

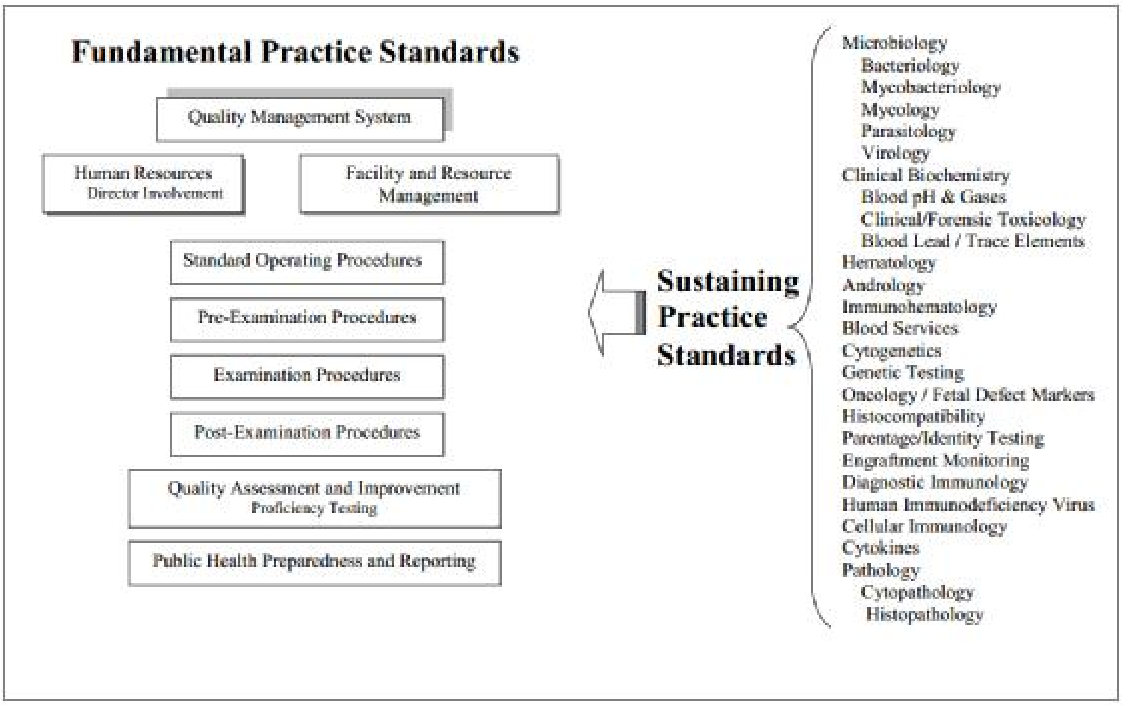

Figure 8. Fundamental practice standards

Source: Rockefeller, N.A. (2008). *Clinical Laboratory Standards of Practice*. State of New York Department of Health.

The fundamental practice standards are shown in Figure 8 and they are valid for all the departments written in the right column. Clinical Laboratory Standards of Practice (2008) makes the practices as the following:

Quality management system outlines the procedures and policies control and enhance the processes that will make a contribution on the laboratory performance in the end.

Human resources arrange the employment of personnel regarding education, credentials, training and experience; all these qualifications would be compatible with the complexity, workload and scope of services; also makes the delegation of responsibilities and ongoing processes.

Director involvement requires effective leadership in order to deliver reliable laboratory services by quality management system. It also verifies and maintains staff competency, responsibilities can be delegated only if duties are assigned by documentation.

Facility and resource management provides maintenance and provision of facilities and resources for analytical processes to be safe and secure.

Standard operating procedures are the accurate description of all procedures that are carried out during pre-examination, examination and post-examination phases of laboratory services.

Pre-examination procedures are policies and practices for proper collection, identification, handling, transport and the acceptance of primary samples for analysis. Obtaining information is significant to the interpretation and reporting of examination results. A validated specimen accession process should be used. Primary sample and sample portions (aliquots) identification and integrity are importance to maintain.

Examination procedures are policies and practices to ensure the initial validation. Examination systems are expected to produce clinically meaningful examination results.

Post-examination procedures are policies and practices to ensure accurate, complete, confidential and factual test results.

Quality assessment and improvement tests whether the practices are convenient with the specifications, or not and includes problem resolution.

In *Proficiency testing participation* process, proficiency test specimens are put in the laboratory's routine workflow and processed in the same manner with the patient specimens.

Public health preparedness and reporting integrates laboratory services with public health programs with the help of policies, procedures and practices.

2.2.2. Medical Laboratory Developments in Turkey

HC services of our country has been improving in the recent years in terms of many aspects such as; infrastructure, manpower, technology and quality. Ministry of health published a study called Hospital Service Quality Standards (HSQS, 2011) with the aim of increasing the performance of health systems. Those standards are recognized for private, public, university hospitals; include many fields and also can be thought as a guidance to carry out the tasks as it should be. HSQS addresses the processes in many aspects, can be used by practitioners as a guidance and also can be used an evaluation criteria. The main aim of the Health Transformation Program, which began in 2003, is to ensure continuous quality improvement in health sector.

Within the scope of the HSQS (2011) there exist a systematic structure which involves sections, departments, standards and evaluation criteria; all the system is organized with a coding system. The intended purpose of the coding system is identifying agencies' level of meeting standards, analyzing and comparing among different agencies. There is a distinction in the description of the standards specified according to the departments that are listed in Table 1.

Table 1.

Departments constituting the vertical sections of HQS

Department Code	Name of Department
	Institutional Service Management
01	Management Services
02	Patient Care Services
03	Control and Prevention of Infections
04	Facility Management
05	Emergency and Disaster Management
06	Information Management
07	Stock Management
08	Waste Management
	Health Service Management
01	Polyclinic Services
02	Emergency Health Services
03	Biochemistry Laboratory Services
04	Microbiology Laboratory Services
05	Pathology Laboratory Services
06	Imaging Services
07	Endoscopy Services
08	Clinics
09	Operating Room Services
10	Intensive Care Services
11	Newborn Intensive Care Services
12	Pharmacy Services
13	Sterilization Services
14	Transfusion Medicine Services
15	Oral and Dental Health Services
16	Physiotherapy Services
17	Dialysis Services
18	Childbirth Services
20	Nuclear Medicine Services
	Support Service Management
01	Patient File and Archive Services
02	Kitchen Services
03	Laundry Services
04	Morgue Services
	Indicator Management
01	Quality Indicators

Source: Hospital Service Quality Standards (2011). General Directorate of Curative Services, Performance Management and Quality Improvement Department. Republic of Turkey, Ministry of Health. Pozitif Printing Press, Ankara.

2.2.3. The Standards for Biochemistry Laboratory Service

In this part some examples of standards will be explained, which belong to one of the Health Service Departments; Biochemistry Laboratory Services (BLS). The full text in HSQS, 2011 involves standards of every single process, procedure and policy within a Biochemistry (BC) laboratory. The following standards are mostly the ones that will be examined in the scope of the application part of this study. Only a certain part is included, because the intent here is to give an idea about the structure. The standards involve each and every step in all of the sub processes of the whole service in order to implement all the tasks as required to provide the desired quality level and not to allow errors to exist within the system.

Test guide shall be available including time of test performance, sample type, information about tests requiring prior preparation, sample acceptance and refusal criteria, proper sample collection and suitable transfer of samples, proper labeling of sample containers, durations for result giving.

Arrangement shall be made for sample collection and their transfer. Date and time of sample collection shall be available. Relevant staff shall be trained on sample collection and transfer. Samples shall be delivered to sample acceptance unit and the followings shall be available at the Hospital Information Management System (HIMS): the department sending samples, delivery date and time of samples, samples shall be evaluated against acceptance and refusal criteria for samples refused, information on reasons for refusal and the person refusing shall be available in HIMS, reasons for refusal shall be monthly analyzed, corrective preventive activity shall be initiated when required, date and time of sample acceptance by the laboratory shall be available in HIMS.

Arrangement shall be available for test procedures; the written arrangement shall include the followings: test procedures, quality control activities, approval of results, arrangement shall be made for devices available at the laboratory.

Performance evaluation for laboratory processes shall be made. Monthly evaluation related to pre-analytic, analytic and post-analytic processes shall be made. Necessary corrective preventive activities shall be initiated according to the evaluation results.

Arrangement shall be made for patient result reports. Patient result reports shall include the followings: date, time and place of sample collection, sample acceptance by the laboratory, the approval of the result. Result giving durations shall be determined for routine and urgent tests. Patient and relevant staff shall be informed on result giving durations.

Laboratory where the tests are analyzed shall be evaluated in terms of meeting service quality standards. From Biochemistry Laboratory Service Quality Standards; service providing agency shall be evaluated at least twice a year by the hospital.

2.3. Queuing

In this section, general information will be given about queuing and its system characteristics will be explained, which are arrival, queue and service characteristics.

2.3.1. General Information about Queuing

As most general expression, "queue" is a line of whether people or any items awaiting for service or processing. The concept of queue has been studied for a long time as a research topic. As long as people face queues in many parts of everyday life, it needs to be studied and never becomes out of fashion. Substantial part of our time is spent on waiting in queues in daily life. This happens at supermarkets waiting for paying, at hairdressers waiting for hairstyling, at restaurants waiting for the service, at hospitals while waiting to be treated by doctors and so on. The queues do not have to be formed of people all the time; they may be made up of either people or items. Broken m/c's waiting in the line to be repaired, programs to be run in a computer system, automobiles at highway toll booths, semi-products waiting in the assembly line to become end products are exact examples of queues which do not consist of people.

The reason of queue existence is simply having demand more than supply at a specific time. In other words, when demand cannot be satisfied instantly due to the number of waiting people or items in the line, a queue occurs. This happens in most of the branches of both service and manufacturing sector. If this situation cannot be managed properly, it causes various kinds of losses for the organizations such as customer defection, difficulties at work flow or system disorder. The losses can be at the individual levels as well as the organizational levels.

In queue systems, satisfying demand in the minimum duration with the minimum cost constitutes the basis. Organizations should use some techniques to attain the aforementioned aim. By means of those techniques efficiency should be increased, the sources should be used optimally and the costs should be decreased to the minimum level. The main purpose of dealing with queues is to set the balance between the waiting time and the service idle time. This trade off is crucial because one of them increases the speed of the system and customer satisfaction while the other one increases the costs. Therefore, organizations should make the right decisions related to system capacity, number of m/c's, working hours, the design of the production or service line in order to increase the efficiency of the process.

2.3.2. Queuing System Characteristics

Queuing Systems have three kinds of characteristics, which are called Arrival Characteristics, Queue Characteristics and Service Characteristics. Detailed explanation about each characteristic is the following.

2.3.2.1. Arrival Characteristics

Under the heading of Arrival Characteristics there are three components which are Size of the Arrival (Source) Population, Behavior of Arrivals and Pattern of Arrivals (statistical distribution).

Beginning with the Size of the Arrival Population, it exhibits two types of characteristics: either unlimited (essentially infinite) or limited (finite). The population size is called unlimited when the number of customers or arrivals waiting on the line at a specific time is only a little proportion of the whole potential arrivals or there are infinite numbers of virtual arrivals that can request the service. Many of the queuing models assume such populations. Customers waiting on the queue to get service from customer relationship manager or shoppers on the waiting line to make the payment can be given as examples. When there is a restricted number of potential arrivals of the service, the population size is called limited, which usually have more complex structures. In that kind of queues, if one or more of the customers have a problem related to usage like broken m/c's, it affects the system's arrival generation capacity (Heizer and Render, 2011, p. 773).

Behavior of Arrivals is actually related with the attitude of the customers holding on the line towards the waiting time. The majority of the queuing models suppose that the customers wait until they are served, do not replace between the lines or do not quit the queues. In the point of fact, this may not be the case, arrivals tend to balk or renege. Customers, who show the attitude of balking, do not even come into the waiting line because the queue seems too long at that moment. Customers who renege join the queue at first, but quit before being served. Both kind of arrivals emphasize the necessity of studying the field of queuing theory (Winston and Albright, 2001, p. 772).

Pattern of Arrivals can be explained by the speed of arrivals coming to the system. The customers may arrive at the system with a certain frequency like one shopper every ten minutes, otherwise they may arrive randomly. Random arrival means each and every arrival does not have a connection with each other and cannot be predicted in anticipation. Poisson Distribution is used in most of the queuing problems in order to forecast the number of customer arrivals per unit time (Heizer and Render, 2011, p. 774).

2.3.2.2. Queue Characteristics

Queue itself is another important part of the queuing systems and defined within the frame of two characteristics. First one is the length of the queue; it may be limited or unlimited. Limited queues cannot be composed of infinite number of customers due to some restrictions like clients waiting in a bank branch with limited waiting chairs. There may also exist unlimited length queues which do not have any restrictions. The second characteristic is related with the Queue Discipline which explains the order principle of getting service among the customers. The most common discipline is First Come First Served (FCFS) in which arrivals are getting service in the same order of arrival times. A variety of priorities may make those rules invalid like an emergent patient coming to hospital after other patients whose situation does not require immediate treatment (Render, et al, 2003, p. 369).

2.3.2.3.Service Characteristics

Service Characteristics is the third important part of the queuing systems and defined within the frame of two characteristics which are design of the service system and the distribution of service times. Number of servers and number of phases determines the system design. If a service system has one line and one server, it is called single-channel queuing system. Service systems with one waiting line and several servers are called multiple-channel queuing systems. If customers visit only one station and quit the system, that system is named as single-phase system. However, if the station number is more than one, that one is called as multiphase system (Heizer and Render, 2011, p. 775).

Service time distribution is another identifier characteristic of queuing systems. The term is related with the service time spent for each customer is whether constant or not. Those which have constant service time are usually m/c based systems, however most of the cases the service time is randomly distributed (Heizer and Render, 2011, p.775)

2.3.3. Performance Characteristics of a Queuing System

When evaluating performance of a queuing system, there exist three standpoints, which are from customers, servers and managers of the system. For the customers, a system is successful, if it has short waiting times and service time. Servers' being neither too busy nor too idle is preferable. For a system supervisor or manager, the system should be working in balance that servers would not remain idle and customers would not wait so long. Performance of a system can be evaluated, however what to do in order to exhibit better performance is another discussion topic. The performance characteristics are waiting time, waiting-line size, time-in-system, number-in-system, lost customers, server utilization and terminology difficulties (Tanner, 1995, p. 39).

CHAPTER III

SIMULATION IN MEDICAL SYSTEMS

Literature review, previous relevant studies and simulation in health systems are examined in this section.

3.1. Literature Review

For a long while HC costs are ranging at significantly high levels for HC organizations, nevertheless patients should be served with an improved quality. The survey of Jun, Jacobson, and Swisher (1999) researches the use of discrete event simulation (DES) modeling in HC systems such as; emergency departments, hospitals, outpatient clinics and pharmacies. Most of the simulation studies presented in the paper researches the relationship between numerous inputs with the HC systems and they are classified under the headings of *Patient Flow* and *Allocation of Resources*. According to the authors efficient and effective patient flow depends on low patient waiting times, low clinic overtime, high patient throughput while keeping the staff utilization in a proper rate and minimizing the idle times. The three issues studied mostly to regulate patient flow are patient scheduling and admissions, patient routing and flow schemes, scheduling and availability of resources. To be concerned with the allocation of resources is also a crucial subject since resources are closely tied with the costs. Allocation of resources is divided into three areas which are bed sizing and planning, room sizing and planning, staff sizing and planning. Each of the areas is discussed individually in the article.

In the review study of Mielczarek and Mydlikowska (2010) the computer simulation models performed beforehand were illustrated, which are made use of in the HC sector. All HC units should realize two objectives that are somehow contrast to each other: satisfying the medical service demands of an expanding population and preserving the costs in a limited range. In the study, HC topic areas and simulation methods that are used are classified, and a comprehensive taxonomy was generated. In their study 168 papers are analyzed that are published in proceedings from recognized international conferences and peer-reviewed journals from 1999 to 2006. According to the study, simulation serves for a wide range of problems related to HC management issues and application areas of simulation are generalized in five categories. Mielczarek and Mydlikowska (2010) expresses that "Models are created: (1) to support global health policy, to evaluate treatment and intervention programs, to forecast the epidemiological trends of chronic diseases, infectious diseases, cancer, and heart diseases; (2) to improve the performance of HC systems using comprehensive diagnosis, to assess the impact of potential organizational changes, to analyze administrative issues such as staff scheduling, appointment schemes, and resource allocation; (3) to estimate and assist with future resource requirements in the context of business planning; (4) to support operational decisions in medical practice; and (5) to assess HC systems' preparedness and efficiency in cases of extreme events."

Table 2.

Simulation methods used in the published models

Simulation Method	Number	Percentage	1999 and before	2000	2001	2002	2003	2004	2005	2006 and after
Discrete-event	118	75.64%	15	9	9	18	19	12	17	19
System Dynamics	23	14.74%	1	1	3	3	1	2	6	6
Monte Carlo	15	9.62%	0	1	1	2	2	5	2	2
Total	156	100%	16	11	13	23	22	19	25	27

Source: Mielczarek, B., & Mydlikowska, J. (2010). Application of Computer Simulation Modeling In the Health Care Sector: A Survey. *Simulation*, 88(2), 197-216.

Table 3.

Distribution of simulation methods among five distinguished application groups

Simulation Method	Total	Group 1	Group 2	Group 3	Group 4	Group 5
Discrete-event	118	23	76	8	1	10
System Dynamics	23	19	2	0	2	0
Monte Carlo	15	12	2	0	1	0
Total	156	54	80	8	4	10
Percentage	100%	34.62%	51.28%	5.13%	2.56%	6.41%

Group 1: epidemiology, health promotion, health policy; Group 2: health and care systems operations; Group 3: health and care systems design; Group 4: medical decision making; Group 5: extreme events planning

Source: Mielczarek, B., & Mydlikowska, J. (2010). Application of Computer Simulation Modeling In the Health Care Sector: A Survey. *Simulation*, 88(2), 197-216.

Table 4.

Distribution of discrete-event simulation method among six sub-groups of health and care systems operations groups (Group 2)

Group 2	Group 2.1	Group 2.2	Group 2.3	Group 2.4	Group 2.5	Group 2.6
76	25	16	5	10	7	13

Group 2.1: effect of organizational changes; Group 2.2: system diagnosis; Group 2.3: staff scheduling Group 2.4: optimal capacity of the resources; Group 2.5: resource allocation; Group 2.6: appointment systems

Source: Mielczarek, B., & Mydlikowska, J. (2010). Application of Computer Simulation Modeling In the Health Care Sector: A Survey. *Simulation,* 88(2), 197-216.

Table 5.

Distribution of simulation methods among the sub-groups of epidemiology, health promotion, health policy group (Group 1)

Simulation Method	Group 1	Group 1.1	Group 1.2	Group 1.3
Discrete-event	23	8	9	6
System Dynamics	19	14	0	5
Monte Carlo	12	6	3	3

Group 1.1: health policy evaluation; Group 1.2: evaluation of intervention and treatment programs; Group 1.3: expansion of infectious diseases

Source: Mielczarek, B., & Mydlikowska, J. (2010). Application of Computer Simulation Modeling In the Health Care Sector: A Survey. *Simulation,* 88(2), 197-216.

Table 2 shows that 118 out of 156 models have been developed by DES and it is the most used simulation technique by far. It can be interpreted from Table 3 that DES is the most preferred method in all groups except for the Group 4 (medical decision making). Group 2 (health and care systems operations), Group 3 (health and care system design) and Group 5 (extreme events planning) are intensively analyzed by DES. Group 1 (epidemiology, health promotion, health policy) had analyzed also by System Dynamics (SD) and Monte Carlo method at a frequency that cannot be underestimated. If Group 2 is divided into six subgroups, from Table 4 it is seen that DES is frequently used in Group 2.1 (effect of organizational changes) and Group 2.2 (system diagnosis). When Group 1 is divided into 3 subgroups which are Group 1.1 (health policy evaluation), Group 1.2 (evaluation of intervention and treatment groups) and Group 1.3 (expansion of infectious diseases); the frequency of DES, System Dynamics and Monte Carlo simulations can be seen for each and every subgroup in Table 5. It can be concluded that for Group 1 in total, DES and SD were widely used.

Mielczarek and Mydlikowska (2010) also stresses that DES is generally used for simulating disease progress with the aim of analyzing treatments, prevention alternatives and other interventions. They claim that DES is a proper method for realistic stochastic problems since it can deal with complexity, uncertainty and variability. SD models provide gaining insight into the dynamics of the disease and the spread of the infection. It creates a general perspective to the problems instead of an individual sight and can be addressed for both qualitative and quantitative problems for large and complex systems.

3.2. Previous Relevant Studies

Related studies done in the area of simulation in HC are given place in this part. Simulation in health systems and simulation in medical analysis laboratories are examined under different headings.

3.2.1. Simulation in Health Systems

Moreno, et al. (1998) defended the opinion that the design of the system in complex organizations must be well known, information should be clear and interdisciplinary teams must integrate with each other intensively for a successful management. An efficient information system eases the decision making process for the hospital management. Within the scope of their study, a hospital is simulated in a patient-centered manner after defining the structural information about the hospital performance, the effects of the control actions and availability of resources. The simulation model imitates the patient flow within various departments of hospital. This simulation tool made it possible to get information via graphs or reports related with the hospital for the hospital management. Also it enabled to try several control actions, see the results and decide what to implement actually.

Swisher, et al (1999) illustrated a DES model of a physician clinic utilizing Orca Computer, Inc.'s visual simulation environment with the purpose of reaching cost-effective, high-quality medical environment. The model developed in this study includes both the transactions of a family practice HC care clinic and a centralized information center. Meanly, the internal and external clinic operations are examined. Object-oriented paradigm was applied in the model which enables the objects of the simulation to be reused through the study. What-if analyses on facility design and staffing levels were conducted; different operating hours, scheduling policies were tried and their results were interpreted. The results derived from the computer runs can be used for reshaping the structure of the clinics, but the main issue at this point is not sacrificing profitability and service levels of the existing system.

Virtue, Kelly and Chaussalet (2011) tried to use simplified DES models for HC applications. They argue that average simulation times can be taken as estimators for real duration of stay and try to show whether if average process time models could be made use of when structuring the emergency service care models, or not. It is also claimed in the paper that average process time models are worthwhile because of their transparent, simplified structure and reduced development durations. After the model validation and verification, the assertions are confirmed. In the application part of the paper, simulation results and numerical data illustrates the backstage of the related ideas.

Norman (2012), in his study about systematic review of the literature on simulation, explains the reasons of necessity to simulation in nursing education. Firstly, it is not practical for educators to demonstrate the nursing students all the diagnoses. Also patients do not spend much time at hospitals; clinic sites are not many in number and clinic hours are fewer due to the faculty shortage. For all these reasons, students do not always have the opportunity to have the required clinical experiences (Rhodes & Curran, 2005). According to the study of Norman (2012), the literature on simulation in nursing education can be divided into three categories, which are internal outcomes, external outcomes and clinical evaluation. The internal outcomes depend on learners' perception such as satisfaction, self-confidence and clinical judgment, whereas external outcomes can be defined as the elements that are learned like safety, communication, knowledge, and skills. The evaluation typed studies are interconnected with the aforementioned internal and external outcomes.

3.2.2. Simulation in Medical Analysis Laboratories

Couchman, et al (2002) made a prediction of the future performance of a clinical biochemistry laboratory by computer simulation. In clinical biochemistry laboratories urine and blood samples are taken from the patients in order to diagnose. In the medium sized general hospital that is studied, it was observed that the workload increased by a 20% in an annual rate. One of the objectives was observing how the laboratory would react to the operational changes like sample delivery times, shift times and determine what changes to implement in order to increase the performance. Second objective was revealing what, building new and faster models instead of the current system, would bring in terms of system performance. The last objective was determining whether installing automated handling would be a logical action when dealing with more volume of samples, or not. The model was constructed using SIMUL8 software package and consists of the abstractions of the real process's entities with the aim of retaining the coherence and decreasing the redundant complexity. After the verification of the model, it is concluded that in order to sustain a satisfactory service level; investment is required in resources, faster analyzers and automated handling is also necessitated.

Mendonca, Phibbs, Vandermeer and Pasek (2010) studied on one of Canada's biggest HC facility and interested in the blood specimen order and collection processes. The purpose of the study was to improve the related processes. The analysis was done by means of separating the whole system into sub-systems which are the order, collection, transportation, analysis and result reporting processes of the analytic laboratory tests. The simulation was conducted via Medmodel Software and tested the system efficiency, utilization and effectiveness. Due to the simulation results, recommendations were generated to reduce the patients' length of stay and the blood specimen error. The biggest limitation to the study is the deficiency of validation of the simulation, which shows the degree of reflecting the existing system. Another limitation is being unable to obtain rigid, reliable and congruent data from the central information system because of disintegrated information systems.

Morales (2011) used DES to model a specific part of the medical laboratory of a medium-large medical facility. The focus is on the processors working in the laboratory whose tasks are receiving the samples, entering the data into the computer system and delivering the samples to the related departments for analysis. The main aim of the study is simulating processors' activities in order to evaluate different ways of operating and observe the potential outcomes. The impact of raising or reducing the number of patient samples to be labeled is also examined. According to the application results, the optimal number of processors was suggested in order to keep the total time of the samples minimum in the system. Also some recommendations were given to regulate operational structure. In this particular project only one part of the medical laboratory was studied and it is thought that expanding the scope by including the medical laboratory completely with all of the m/c’s would be more useful and insightful in terms of applicability.

Lote, Williams and Ülgen (2009) dealt with a medical laboratory and aimed to improve its operational efficiency, financial efficiency and service level to its clients. Optimal resource allocation via DES is tried to be achieved and Enterprise Dynamics Simulation software is used for the study. The anticipated outcomes of the project can be listed as the following: optimizing courier route to enhance transportation efficiency; realizing the interconnection between the level of operational performance and the courier route development; carrying out smoother workload leveling among different departments like microbiology, serology and hematology; providing financial efficiency by means of cost savings due to the redeployment of personnel. Consequently routes are optimized and couriers begin to be used more efficiently, workload leveling is also achieved and these two outcomes provide a huge amount of cost savings related with payrolls.

CHAPTER IV

MATERIAL AND METHOD OF THE APPLICATION

In this chapter, material and method of the application will be presented. The laboratory will be introduced with process details. Problem will be described; workflows will be illustrated; system specifications, assumptions and data collection will be narrated.

4.1. Material

4.1.1. Application Area: Laboratory of a Hospital

The number of personnel working in the laboratory is 105. This number includes medical doctors, faculty members, postgraduates, nurses, technicians, laboratorians, secretary and personnel. Working hours of the laboratory is eight hours routinely. For tests ordered for emergency department, laboratory works nonstop for 7 days / 24 hours. Blood and urinary tests are processed predominantly in the laboratory. Other tests are done on throat cultures, gaita, mucus and all body fluids. It composed of biochemistry, microbiology, immunology and serology laboratories.

There are more than hundred types of tests that are being studied routinely in the laboratory. The information of each and every test is kept in the hospital database. The data includes all of the system details. Before the sample is taken from the patient, a barcode is pasted on the tube and that barcode contains the related information such as the type and number of ordered tests, patient identification, the times when the tube passes by where and the duration. If the services, which the samples go through, are called as work stations, the exact time of the visit in each work station is recorded by barcode readers.

To summarize the whole process that will be studied in the scope of the study very briefly, the very first action in the process is the order made by the clinicians for the patients in the services, then registration is done in the order acceptance department, at the blood-letting department barcode is put on the tube, sample is taken from the patient, sample is sent to the laboratory by pneumatic system, which is also called air tube system. An infrastructure is established within the hospital consisting a tube system which enables secure and fast transportation among various departments. The working principle is transporting by using the air pressure and pneumatic system provides speed, security and low cost. To continue with the process, sample acceptance is done in the laboratory entry, the sample is oriented to the related unit, enters the automation, been analyzed, its result is approved, reported and saved in the system.

In the laboratory, there is an automation system, apart from the numerous individual test m/c’s, consisting of centrifuge, hormone and biochemistry test m/c’s. The centrifuge m/c is the first station that blood tubes stop by and it separates out the blood components, the components differ by their densities. Red blood cells sink to the bottom of the tube because it is the densest; the buffy coat contains the most thrombocyte inside and stays in the middle; the plasma is the least dense part and rises up to the top of the tube. After the centrifuge two hormone m/c’s are installed and beside four biochemistry m/c’s take place.

4.1.2. Problem Description

In this section work flows will be presented in detail, assumptions will be expressed and stages of data collection period will be demonstrated.

4.1.2.1. Work Flows

The process begins with doctor’s examining patient, making order and patient comes to the order acceptance unit. Patient waits in the line with the order paper in hand which includes the information of the tests ordered by the doctor. When the turn comes they take the order paper, make the acceptance and give a barcode label; the time of that moment is kept in the database. There are four computers doing that work. Figure 9 illustrates order acceptance process. The photographs are taken from the hospital laboratory which can be seen in figure 9, 10, 11, 13, 14 and 16.

Figure 9. Order acceptance unit

After that another waiting line exists for blood-letting. There are six nurses in the blood-letting unit and the barcodes are also read by the computer system in that specific time of blood-letting. Figure 10 shows process of blood-letting process.

Figure 10. Blood-letting process

The blood tubes are sent to the laboratory within pneumatic system. When the tubes arrive in the laboratory entrance, sample acceptance unit meets them; system reads barcode in order to keep the record of the exact time of entrance to the laboratory. In sample acceptance unit, one computer does the work. The tubes scanned by barcode readers are placed in the racks to be delivered to the automation system which has rail system, if there is no problem with the sample.

Figure 11. Rail system of the automation

In case of the following reasons; inaccurate material, insufficient material, missing tube, damaged sample, wrong barcode, insufficient information, registration failure, unrecorded sample or sample without barcode, sample is denied. If problem is barcode related, sample turns to the order acceptance unit. Otherwise, it means that problem is sample related, then it goes back and repeats blood-letting and follows the same route. Figure 12 illustrates the workflow of the laboratory.

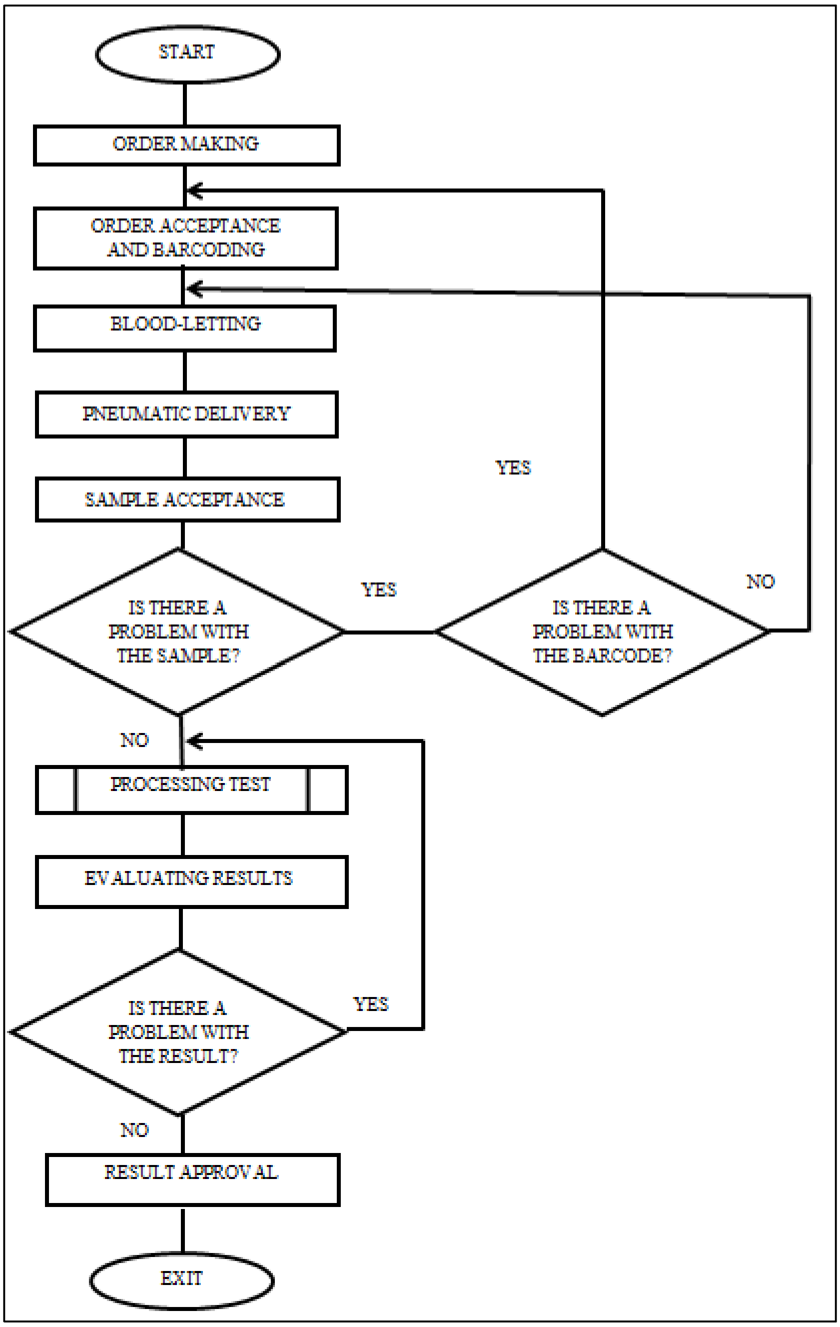

Figure 12. Workflow of the laboratory

During the entrance to the automation system, barcodes are read again and tubes introduce the system one by one on the rail system. The first m/c is centrifuge where all of the tubes get in. It takes the tubes five by five and has capacity of forty tubes at once and process time is 270 seconds. It begins processing after waiting for maximum of four minutes for five tubes to come. It can begin in less than four minutes if five tubes come; or it can start processing after four minutes with only one tube using one fifth of the capacity. Figure 14 illustrates working of the centrifuge machine.

Figure 13. Machine loading

Figure 14. Centrifuge machine

If any hormone will be tested, the tube is directed to one of two hormone m/c's. Hormone m/c takes the tubes one by one and process time per tube is approximately twenty seconds. Then, if any BC test is ordered, tube goes to one of the three BC m/c's. Processing time depends on the type of tests and takes four tubes at once. Like centrifuge it begins processing after waiting for maximum of four minutes for four tubes to come. It can begin in less than four minutes if four tubes come; or it can start processing after four minutes with only one tube using one fourth of the capacity. The fourth BC m/c is at the end of the automation system, as distinct from the first three it tests the medicine level. Also it can be used manually for the tubes that have insufficient level of blood serum. Figure 15 shows the sub-processes of testing.

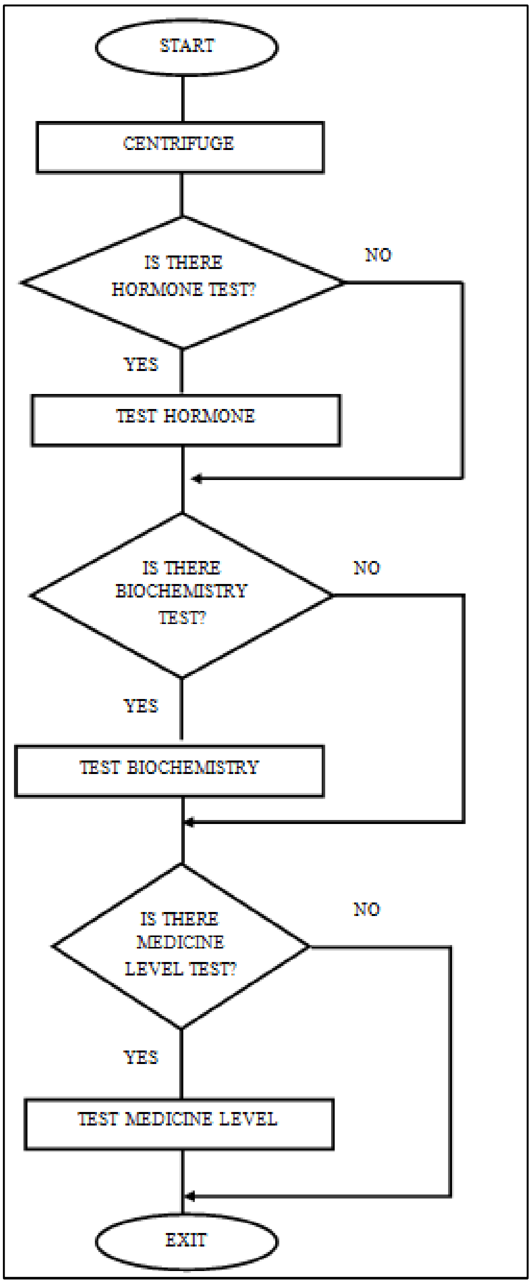

Figure 15. Sub-Processes of testing

Figure 16. BC Machine

After tests are completed and results are evaluated, if there is inconsistency of the result with reference ranges or patient illnesses, the result is refused. In that case sample reenters the system and is tested once again. If everything is normal, the result is approved and the sample exits the system.

4.1.2.2. Assumptions

Delivery from sample acceptance unit to automation system observed at different hours in different days, expert opinion is taken and time consumed for this action is one to three minutes on average.

BC tests are processed in the same m/c however each test has a time interval for processing. Maximum process time is 720 seconds for BC tests and maximum number of tests studied on 1 sample is 25. Therefore, processing time for BC machine is defined as 720/25*(number of BC tests) on average.

The resource used for transfer from blood-letting unit to sample acceptance unit, which is the pneumatic system, is assumed to be always sufficient.

In hormone and BC machines, samples that have problem are assumed to reenter the system with the probability of 50%. This assumption is made by the help of an expert opinion.

4.1.2.3. Data Collection

The numerical data set is withdrawn by SQL (Structured Query Language) from the database of the laboratory that has a time period of one year. Data includes file ID of patients, sample ID of the blood, department where the order is given, test name, in which m/c the test is done, the exact time of order making, order acceptance, blood-letting, sample acceptance when entering the laboratory, m/c loading, m/c exit and result approval. The data related with the structure, system, processes and procedures were obtained by direct observation of the pre-examination and examination processes, interview with the laboratory personnel and managers and also time keeping method on individual laboratory processes.

4.2. Method

4.2.1. Arena Model

Arena simulation software is used for analyzing the effects of what-if applications and strategies in anticipation of implementing. When the aim is efficient, effective and optimized performance, Arena simulation is a reasonable option to use simce it predicts and evaluates the system strategies. The ultimate goal is increasing the overall business performance.

The results of the computations made in previous sections are used in this part while designing the simulation model. The model begins with order arrivals made by doctors; includes processes of order acceptance, blood-letting, transferring to the laboratory by pneumatic system, sample acceptance, transferring to the automation system, loading tubes to system, waiting for centrifuge in the queue, centrifuge, hormone testing, BC testing process, medicine level testing, exit from the automation, and result approval. Distribution parameters are entered into related modules. The number of tests that will be processed on each and every arriving entity is attributed on. Another attribute labeled on the entities is the sequence of the machines that they will be processes in; that is which tests will be measured. Transferring by pneumatic system lasts for 30 seconds. When sample comes to the sample acceptance unit, there is a probability that it is not proper and may be refused. If sample is valid, it continues; if not, it is discarded from the system. Tubes are accumulated until their number reaches 32, then transferred to automation and enters one by one to the system. All of the tubes stop by the centrifuge machine, after that if any hormone, BC or medicine level will be tested; the tube goes to the related machines, respectively. There is possibility that hormone and BC test results are not valid. The problematical tubes are directed to the medicine machine and tested one more time. After testing, samples exit from the automation, go to result approval process and total time spent in system is recorded. Replication length is taken as 90 days. The arena model is illustrated in Figure 17.

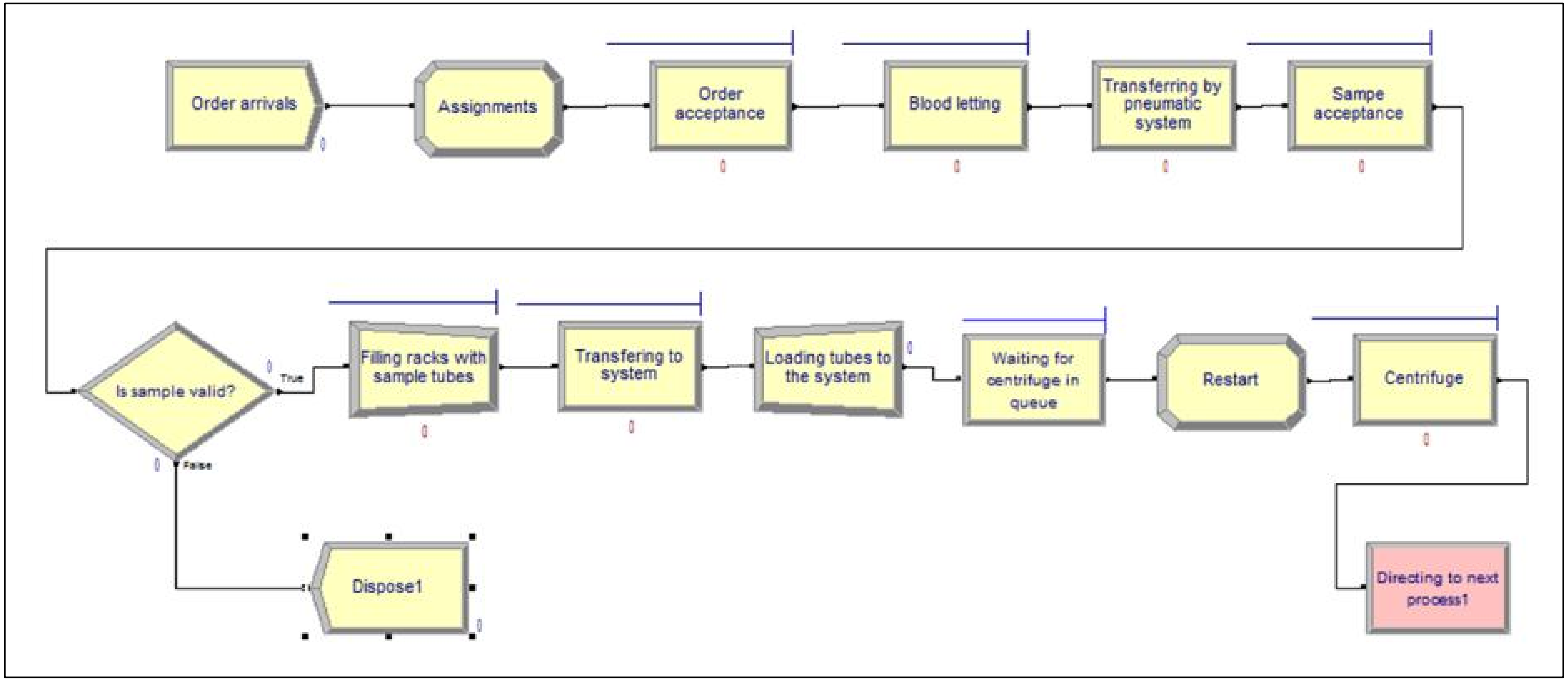

Figure 17. Arena Model

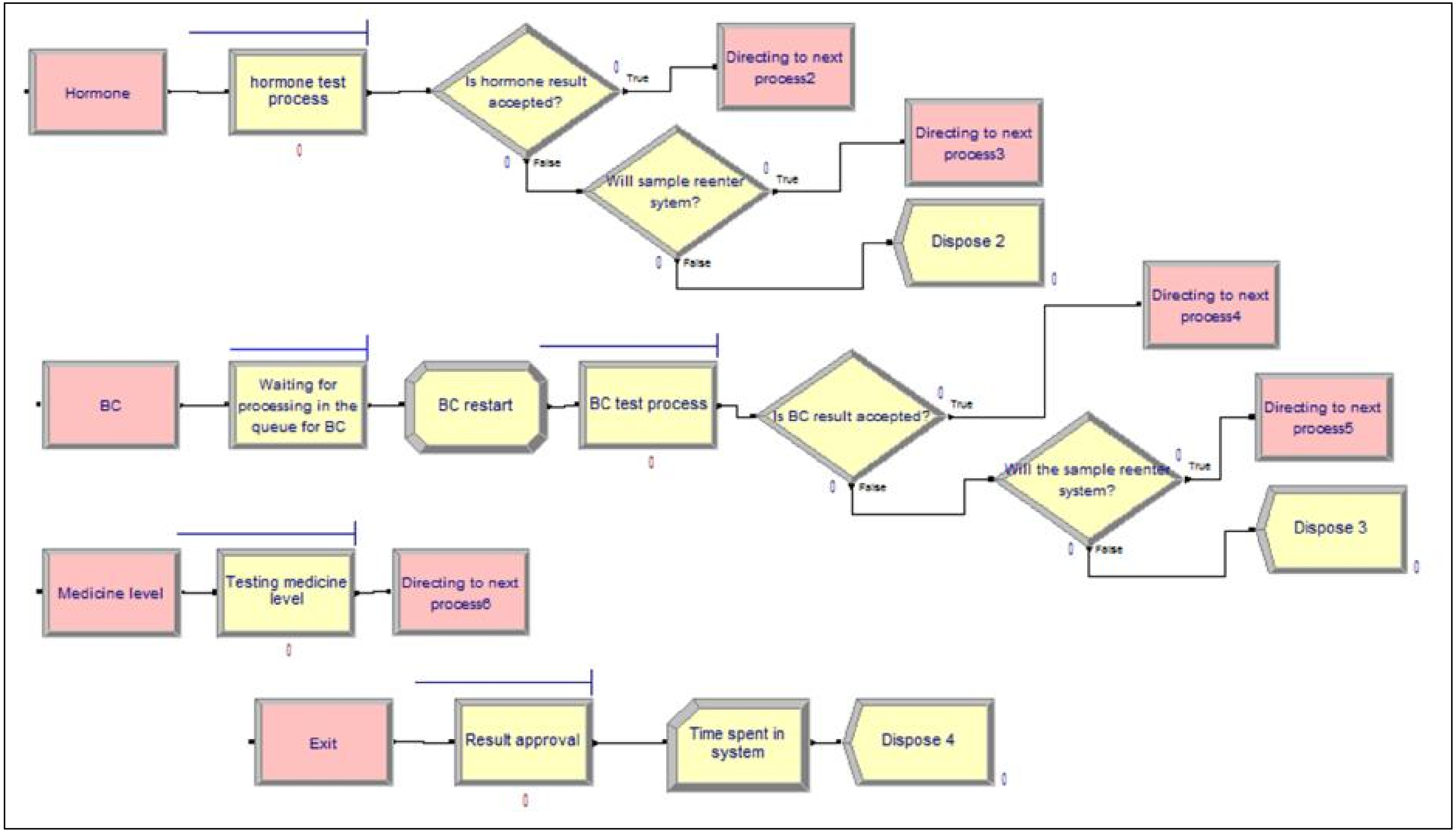

Figure 17. Arena Model (cont'd)

4.2.2. Output Analysis

Output analysis is a phase of simulation in which replications are designed, statistics are calculated from them and those statistics are presented. Main intend of output analysis is evaluation of simulation results and it addresses three main concerns. First one is a good replication design; second one is estimation of performance metrics; third one is system analysis and experimentation. When simulation begins running, the initial period is named as warm-up whose values can bias long term statistics because simulation starts with no level of queues. Collecting statistics after warm-up period and distinguish them as junk is reasonable in order to reflect the system accurately (Altıok and Melamed, 2007, p. 165).

4.2.2.1. Warm-up Period

According to Robinson (2007) the initial transient issue in simulation is a significant topic for which different techniques are applied. One of them is running the simulation for a warm-up period and excluding data of that specific period. Various methods are used for the purpose of determining warm-up period. The hardship here is deciding on the length of the warm-up period. In the case of underestimation, simulation results would be probably biased. If it is overestimated, output data would be wasted. The methods can be classified as; graphical methods, heuristic approaches, statistical methods, initialization bias tests and hybrid methods. Graphical methods are based on the visual inspection of time-series of the simulation output. They are simple, open to human interpretation and judgment.

In this study, Welch method will be used to determine the warm-up period, which is one of graphical methods. Arena simulation model is run for 30 times, with replication lengths of 1 to 30. For each and every run, time spent in system is recorded, moving averages are calculated by using W_{10} and graphic is plotted. In Figure 18, average time increases up to some point, after that it is somehow stabilized with minor up and downs. That point is the warm-up period, which is 16 in this particular case. This means; after 16th day, the model begins behaving more similar with the system. First 16 day will not be taken into any consideration or calculation by the simulation program. Figure 18 shows the graphic of average time spent in system with different replication lengths.

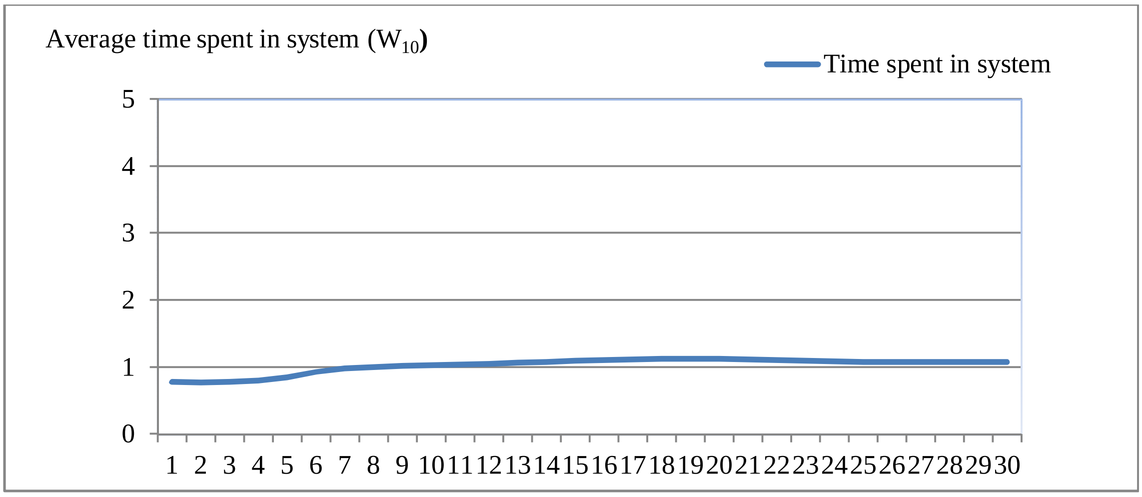

Figure 18. Average Time Spent in System with Different Replication Lengths

4.2.2.2. Number of Replications

When terminating simulation models, number of replications is a determinant factor since sample size depends on it. Number of replications will be determined by the relative error method. If there is an equation like $|\bar{X} - \mu| = \gamma$, then it can be said that $\bar{X}$ has an error of γ, mean percentage error in $\bar{X}$ is 100 γ percent. With a probability of $(1 - \alpha)$, $\bar{X}$ has a relative error of at most $\gamma / (1 - \gamma)$. $n^*_r(\gamma)$ is approximated to be the smallest integer *i* satisfies the condition. With the assumption of both population mean and population variance do not change while the number of replications increases; the number of replications, $n^*_r(\gamma)$ can be determined by the following formula (Law, Kelton, 2000, p. 513).

$$n^*_r(\gamma) = \left\{ i \geq n : \frac{t_{i-1,\,1-\alpha/2}\sqrt{S^2(n)/i}}{|\bar{X}(n)|} \right\} \leq \gamma'$$

Where;

γ' (adjusted relative error) = $\gamma / (1+\gamma)$

n = Number of simulation replications

$S^2(n)$ = Sample variance

$\bar{X}(n)$ = The mean of n resulting independent and identically distributed random variables

α = Level of significance,

t = Critical value of the t-test for n-1 degrees of freedom and significance α

If γ is taken as 0.10, γ' (adjusted relative error) = 0.10 / (1+ 0.10) = 0.09

$$n^*_r(\gamma) = \left\{ 12 \geq 10 : \frac{2.201 \sqrt{0.1591 / 12}}{2.8918} \right\} = 0.0876 \leq 0.09 \longrightarrow i = 12$$

In Table 6, average durations per sample spent in the automation system are listed with different number of replications according to the arena results.

Table 6.

Average time spent in system with different number of replications

# of Replications	Average Time Spent in System
1	4.0180
2	2.8576
3	2.8201
4	2.7782
5	2.6850
6	2.7790
7	2.7444
8	2.7311
9	2.7865
10	2.7182
Mean $\bar{X}(n)$	2.8918
Variance $S^2(n)$	0.1591

4.2.2.3. Verification and Validation of Model

Verification is checking out if the model is constructed correctly in computer or logical structure of the model is accurately represented. Validation is concerned with building the right model and modeling an accurate representation of real system. Independent Sample t-test will be done in order to validate constructed model. SPSS will be used for testing. Data of time spent in system is taken both from the simulation model and observed from the real system in sample sizes of 10. Table 10 shows related data.

Table 7.
Data of time spent in system

Observation #	Simulation	Real
1	4.08	2.2
2	2.13	2.57
3	3.01	3.3
4	3.15	5.1
5	2.69	2.5
6	2.77	3.1
7	2.34	2.8
8	3.3	2.7
9	2.57	3.56
10	2.67	3.4

Hypothesis is determined as the following;

H_0 *:* There is no meaningful difference between time spent in system data of simulation and real system observations.

H_1 *:* There is meaningful difference between time spent in system data of simulation and real system observations.

Simulation values are defined as group 1 and represented by 1; real system values are defined as group 2 and represented by 2. Group statistics can be seen in Table 11. Sample sizes of both are 10. Mean, standard deviation, standard error mean of group 1 and group 2 are 2.871 and 3.123; 0.5526 and 0.819; 0.1747 and 0.259 respectively.

Table 8.
Group statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Time spent in system	1	10	2.871	0.5526	0.1747
	2	10	3.123	0.819	0.259

According to the independent samples test significance levels are 0.4304 and 0.4319 in the situations of equal variances assumed and not assumed, respectively. Results are illustrated in table 12. In both cases p values are bigger than 0.05. This result indicates that there is no meaningful difference between time spent in system data of simulation and real system observations and model represents the real system. In other words, model validation is provided.

Table 9.
Independent samples test

		t-test for Equality of Means				
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Time spent in system	Equal variances assumed	-0.8066	18.0000	0.4304	-0.2520	0.3124
	Equal variances not assumed	-0.8066	15.7868	0.4319	-0.2520	0.3124

CHAPTER V

RESULTS AND DISCUSSION

5.1. Data Analysis

In order to clarify the uncertainties concerning the processes of the system and to prepare the inputs of simulation, a remarkable work was done via excel functions. Firstly, time between order arrivals are calculated and group of more than 100 data was transferred to Statistica -statistics and analytics software package- in order to find the distribution fitting. Process times of order acceptance, blood-letting, sample acceptance, result approval, and testing medicine level are also examined in Statistica; the distributions obtained are illustrated in following figures.

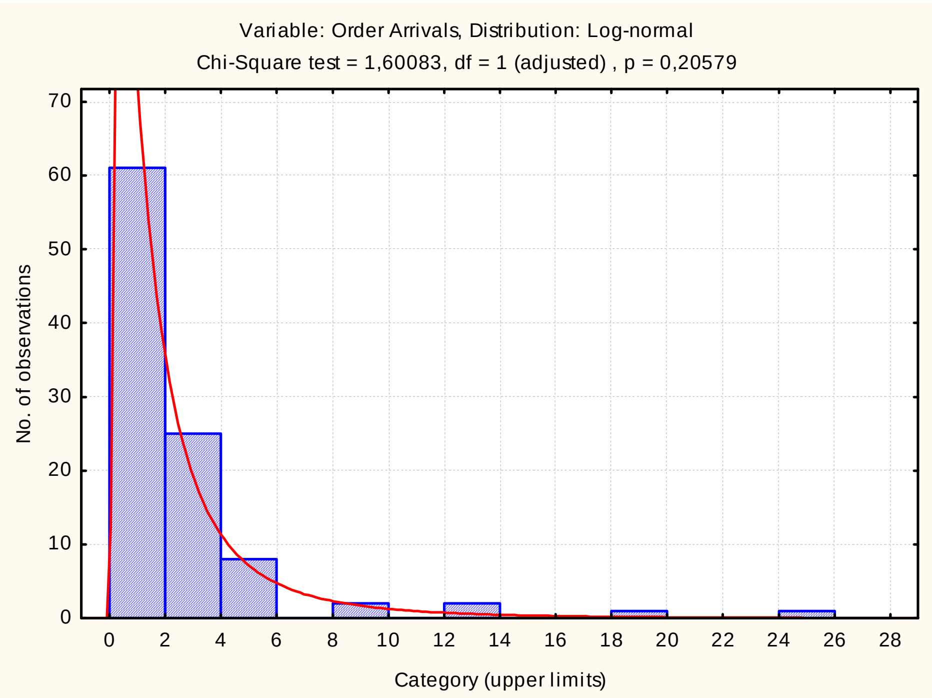

Figure 19. Distribution of order arrivals

Figure 19 shows that time between order arrivals fit lognormal distribution with P-value of 0.20579. The mean is 0.32 minutes and standard deviation is 1.05.

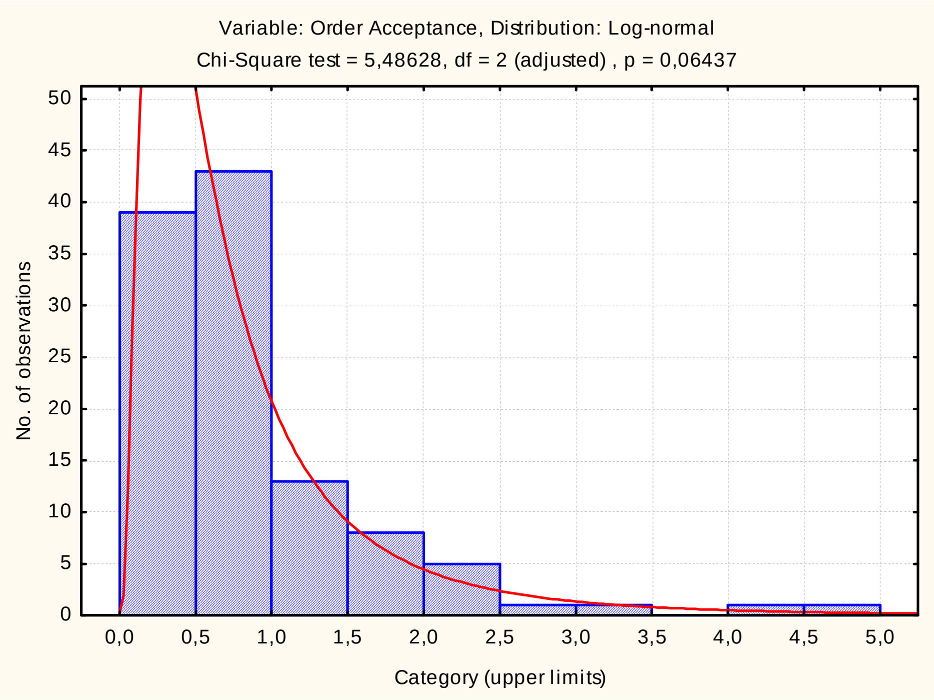

Figure 20. Distribution of order acceptance

Figure 20 illustrates that order acceptance process times also fit lognormal distribution with P-value of 0.06437. The mean is 0.57 minutes and standard deviation is 0.87. Figure 21 shows that blood-letting process times fit normal distribution with P-value of 0.10814. The mean is 114.44 seconds and standard deviation is 50.63.

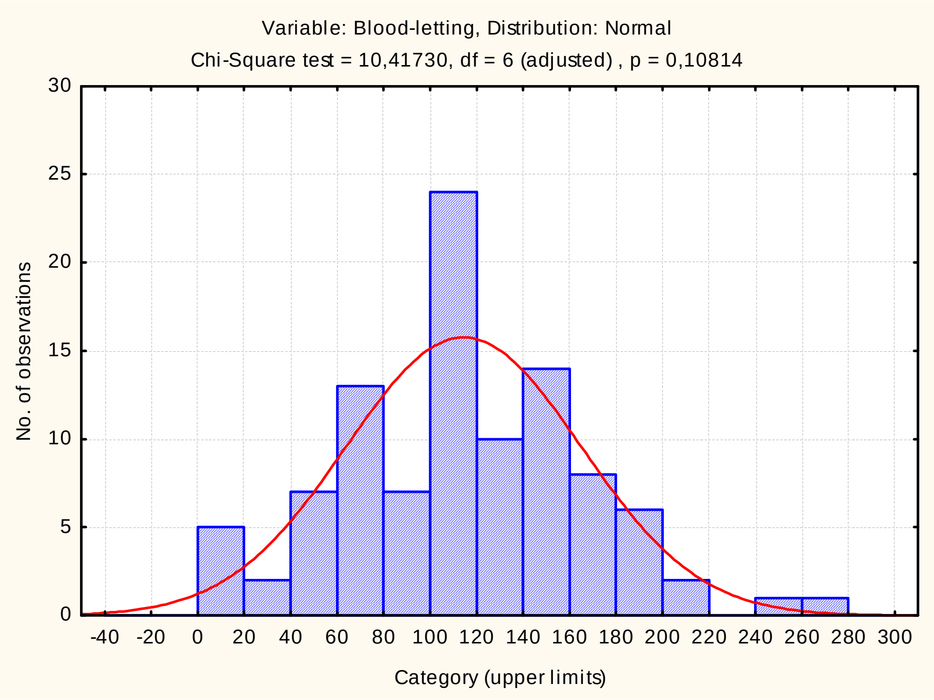

Figure 21. Distribution of blood-letting

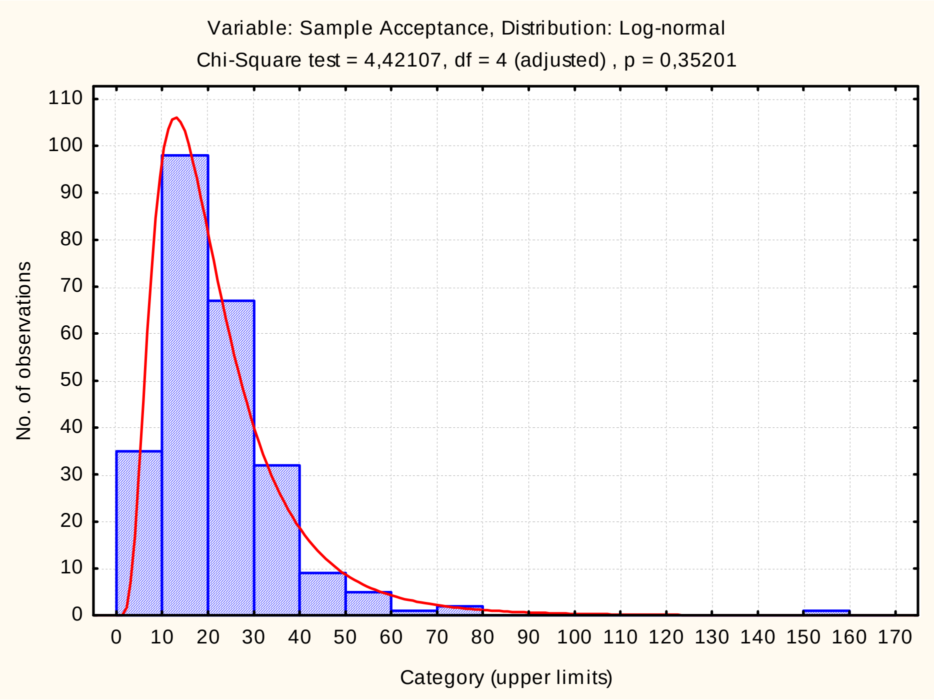

Figure 22. Distribution of sample acceptance

Figure 22 illustrates that sample acceptance process times fit lognormal distribution with P-value of 0.3520. The mean is 2.92 seconds and standard deviation is 0.61.

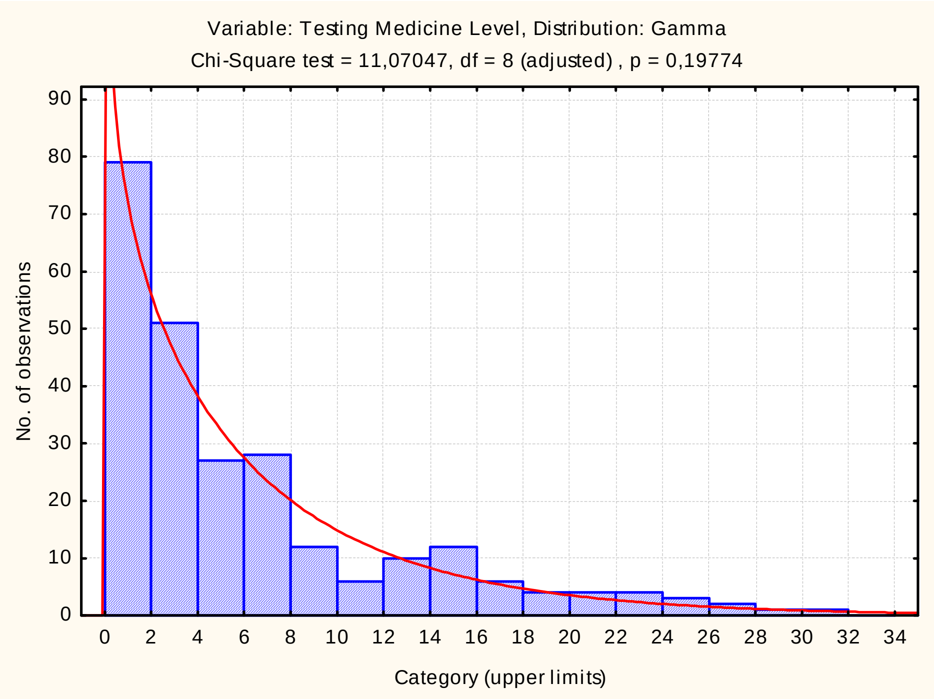

Figure 23. Distribution of testing medicine level

Figure 23 shows that testing medicine level process times fit gamma distribution with P-value of 0.1977. The mean is 7.61 minutes and standard deviation is 0.83.

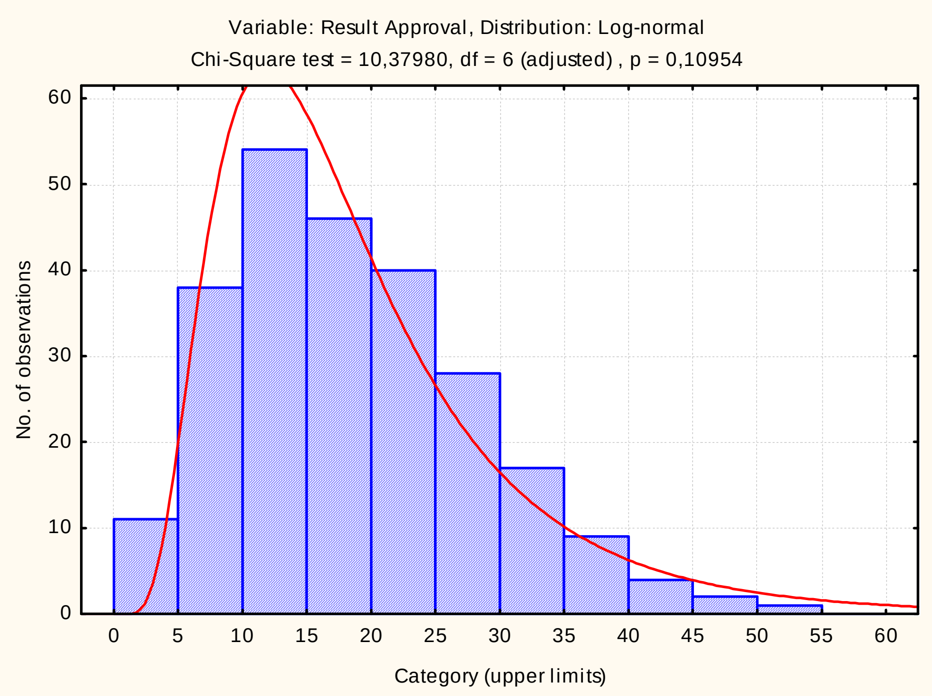

Figure 24. Distribution of result approval

Figure 24 shows that result approval process times fit lognormal distribution with P-value of 0.1095. The mean is 2.79 seconds and standard deviation is 0.57. the summary of Figure 19-24 can be examined from Table 10.

Table 10.

Arrival and process characteristics

	Distribution	P value	Mean	Standard Deviation	Unit
Order Arrivals	Lognormal	0.2058	0.32	1.05	Minute
Order Acceptance	Lognormal	0.0644	0.57	0.87	Minute
Blood-letting	Normal	0.1081	114.44	50.63	Second
Sample Acceptance	Lognormal	0.3520	2.92	0.61	Second
Testing Medicine Level	Gamma	0.1977	7.61	0.83	Minute
Result Approval	Lognormal	0.1095	2.79	0.57	Second

For each and every patient and order only one tube introduces to the automation system besides numerous tests can be processed from that single tube. As aforementioned, process time per sample for hormone test is approximately 20 seconds regardless of how many tests will be studied. However, time spent in the system for BC tests depends on how many and which tests will be studied. The number of tests done from one sample is classified by the help of excel and how many times each number was replicated for different samples and the percentages were also calculated. Therefore, Table 11 shows calculated percentages of the number of BC tests.

Transferring samples from sample acceptance unit to automation system is taken as sometime between 1 to 3 minutes in accordance with observation results.

Table 11.

Number of BC tests per sample

# of tests	# of repetitions	Percentage	Cummulative percentage
1	2838	15.39%	15.39%
2	1182	6.41%	21.80%
3	1037	5.62%	27.43%
4	1367	7.41%	34.84%
5	1383	7.50%	42.34%
6	1227	6.66%	49.00%
7	1449	7.86%	56.86%
8	1004	5.45%	62.30%
9	1127	6.11%	68.42%
10	1298	7.04%	75.46%
11	651	3.53%	78.99%
12	898	4.87%	83.86%
13	591	3.21%	87.06%
14	448	2.43%	89.49%
15	542	2.94%	92.43%
16	479	2.60%	95.03%
17	353	1.91%	96.95%
18	300	1.63%	98.57%
19	87	0.47%	99.05%
20	49	0.27%	99.31%
21	53	0.29%	99.60%
22	36	0.20%	99.79%
23	28	0.15%	99.95%
24	8	0.04%	99.99%
25	2	0.01%	100.00%
	18437	100.00%	

There are possible routes that a tube can follow within the automation system. Due to the structure of the system, one tube can be processed in at most one of the hormone test m/c's but at most two of the biochemistry m/c's. The fourth of the biochemistry m/c can do the same work with the first three biochemistry m/c's, however additionally it can test medicine levels, so there is possibility that one tube can be processed in two biochemistry m/c's, as well as it is possible not to be processed in none of the BC m/c's. Five possible routes are defined as seen below;

Route 1: If the tube is processed in none of BC m/c's and processed in 1 hormone m/c.

Route 2: If the tube is processed in 1 BC m/c and not processed in hormone m/c's.

Route 3: If the tube is processed in 1 BC m/c and processed in 1 hormone m/c.

Route 4: If the tube is processed in 2 BC m/c's and not processed in hormone m/c's.

Route 5: If the tube is processed in 2 BC m/c's and processed in 1 hormone m/c.

Table 12.

Usage Percentage of Routes

Route 1	10.14%
Route 2	44.05%
Route 3	40.78%
Route 4	2.07%
Route 5	2.96%

The percentages of usage rates of the five routes are shown in Table 12. The weights are needed to be determined that represents the usage frequency of the routes. Most used ones are route 2 and 3 with the percentages of 44.05% and 40.78% respectively; then route 1 with 10.14% and route 4 and 5 have thin shares of 2.07% and 2.96%.

There is possibility that processes can be stopped by refusals at some points in the whole system. This can happen at sample acceptance or result approval stage that becomes ‘sample refusal’ and ‘result refusal’. Sample can be denied for the reasons of inaccurate material, insufficient material, missing tube, damaged sample, wrong barcode, insufficient information, registration failure, unrecorded sample or sample without barcode. Sample refusal reasons are illustrated by pie chart in Figure 25. When we look at the real data, 185 out of 520,560 hormone and 100 out of 2,063,755 BC samples are denied which represents rate of 0.040% and 0.005% respectively. The most common result denial reason is inconsistency of the result with reference ranges or patient illnesses. To give a ratio, 1,490 out of 520,560 hormone and 2,280 out of 2,063,755 BC test results are denied which represents rate of 0.30% and 0.11%, respectively.

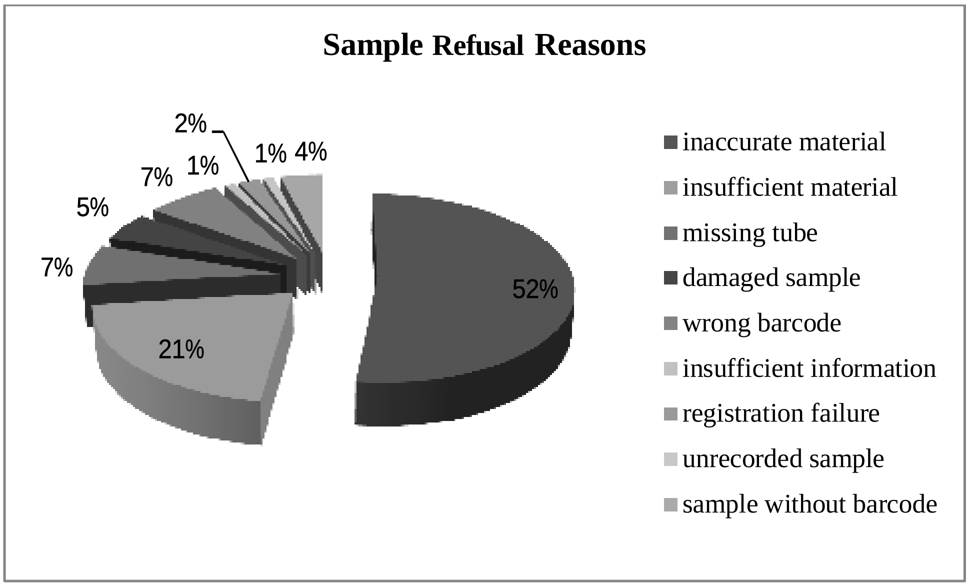

Figure 25. Pie chart of sample refusal reasons

5.2. Results

Simulation model is run with a warm-up period of 16 days, replication length of 90 days and 12 replications. In these circumstances, number out from the system is 131,271; which is approximately 1,460 samples per day and this is a realistic number for the laboratory. Time spent in the system is 2.8112 hours on average, with minimum value of 0.1790 and maximum value of 58.5557 hours.

According to Table 13, an entity which stays in the system for total time of 2.8105 hours, value added time is 0.2200 hours; non-value added time is 0; waiting time is 2.5884 hours and transfer time is 0.0021 hours. This result shows that most of the time is spent on waiting in the whole process.

Table 13.

Entity / time details

Value Added Time	Average
Entity 1	0.2200
Non-value Added Time	Average
Entity 1	0.0000
Wait Time	Average
Entity 1	2.5884
Transfer Time	Average
Entity 1	0.0021
Other Time	Average
Entity 1	0.0000
Total Time	Average
Entity 1	2.8105

When the simulation run is stopped at the end of 90th day, the number of entities had entered the system was 135,926; number out was 135,374 and work-in-process was 527 according to Table 14.

Table 14.

Situation of entities

Number In	Average
Entity 1	135,926
Number Out	Average
Entity 1	135,374
WIP	Average
Entity 1	527

The queues which are composed in front of the processes and average waiting durations of each of the queues are listed in table 15. Blood-letting queue has 2.096 hours of average waiting time. The crowd in blood-letting unit is remarkable and also an indicator of the long waiting times. The longest average waiting time belongs to medicine level testing machine of 6.6213 hours. The length of the medicine level waiting queue can be explained by the machines structural features. It is connected to the automation system like other machines, measures BC levels; additionally measures medicine levels and also it is used manually for the samples of which results are refused.

Table 15.

Waiting durations of the queues

Queues	Average	Minimum Value	Maximum Value
Testing Medicine Level	6.6213	0	29.8586
Blood Letting	2.0960	0	9.1753
Filling Racks with Samples	0.0795	0	5.8618
BC Test Process	0.0263	0	0.1723
Hormone Test Process	0.0219	0	0.0778
Waiting For Centrifuge	0.0215	0	5.9015
Waiting For BC	0.0179	0	5.8562
Order Acceptance	0.0040	0	0.1792
Sample Acceptance	0.0039	0	0.0520
Result Approval	0.0003	0	0.0059
Transfer to System	0.0001	0	0.0018

In each queue, the average number of waiting samples can be seen in table 16. Blood-letting queue is the most crowded one among all other queues with 393.11 of average waiting number. Secondly, testing medicine level machine has an average length of 63.25 samples. After sample acceptance process, during waiting the racks to be filled, there exists another queue of 14.82 in average. BC test, centrifuge, waiting for processing in BC and hormone test phases has queues of 4.41, 4.00, 3.00 and 2.21, respectively.

Table 16.

Number of waiting

Queues	Average	Minimum Value	Maximum Value
Testing Medicine Level	63.24	0	280
Blood Letting	393.11	0	1,704
Filling Racks with Samples	14.82	0	32
BC Test Process	4.41	0	34
Hormone Test Process	2.21	0	27
Waiting For Centrifuge	4.00	0	36
Waiting For BC	3.00	0	30
Order Acceptance	0.74	0	61
Sample Acceptance	0.71	0	16
Result Approval	0.05	0	8
Transfer to System	0.01	0	1

Usage rates of resources are illustrated in table 17. Nurses and medicine level testing machine work with 99.05% and 98.72% capacity, respectively. These rates are very high, which can also be understood from the waiting times. BC machines have the rate of 81.09% which is an acceptable rate. Order acceptance personnel, centrifuge machine, sample acceptance personnel, hormone test machine and result approval personnel has utilization rates of 44.64%, 34.97%, 34.59%, 27.99% and 14.44% respectively, which can be regarded as low rates. Figure 26, shows the utilizations of resources graphically.

Table 17.

Utilization rates of resources

Scheduled Utilization	Average	Minimum	Maximum
Nurses	99.05%	97.66%	99.90%
Medicine Test Machine	98.72%	96.11%	1.00%
BC Machine	81.09%	79.86%	81.83%
Order Acceptance Personnel	44.64%	43.94%	45.09%
Centrifuge Machine	34.97%	34.49%	35.30%
Sample Acceptance Personnel	34.59%	34.11%	34.92%
Hormone Machine	27.99%	27.57%	28.32%
Result Approval Personnel	14.44%	14.26%	14.56%

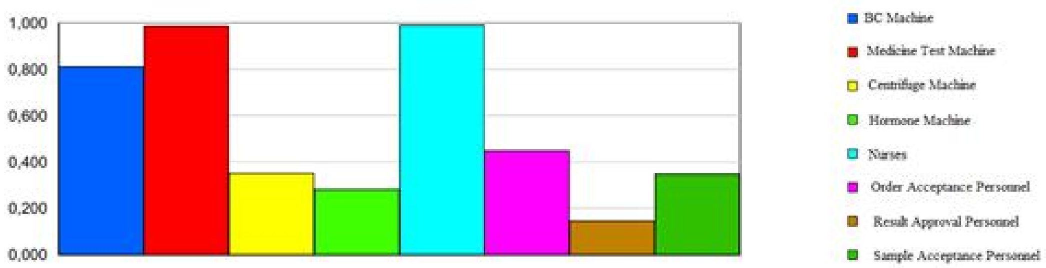

Figure 26. Chart of the utilization rates of resources

BC machine, BC medicine level machine, centrifuge machine, hormone machine, nurses, order acceptance computers, result approval personnel and sample acceptance personnel works with 9.73, 0.99, 13.99,0.56, 5.94, 1.79, 0.14 and 0.34 samples in average out of 12, 1, 32, 2, 6, 4, 1 and 1 respectively. These values can be seen in table 18, occupancy conditions of resources.

Table 18.

Occupancy conditions of resources

Number Busy	Average	Minimum	Maximum
Nurses	5.94	0	6
Medicine Test Machine	0.99	0	1
BC Machine	9.73	0	12
Order Acceptance Personnel	1.79	0	4
Centrifuge Machine	13.99	0	32
Sample Acceptance Personnel	0.35	0	1
Hormone Machine	0.56	0	2
Result Approval Personnel	0.14	0	1

5.3. Recommendations

As it can be clearly interpreted from the simulation results, the bottleneck in the examined hospital processes is the number of nurses. They work with the capacity of 99.05% and there is an average of 2.096 hours waiting in blood-letting unit which is a large proportion of the average time spent in the whole system. In order to decrease time spent in the system, enhance patient satisfaction and service quality, number of nurses should be increased.

The medicine level testing machine works with 98.72% capacity and the waiting time is 6.6213 hours. As it is explained in the previous section, that machine is connected to the automation system like other machines, makes the same tests with BC machines, additionally measures medicine levels and also it is used manually for the samples of which results are refused. Adding one more BC machine may be costly and ineffective; however one of those three workloads can be subtracted from the machine. If routine BC tests are not measured in medicine testing level and that work is shared among three BC machines; waiting time and usage rate will decrease. Hence, the system would be more balanced.

There are two hormone machines and the utilization rate is 27.99%. This means there exists idle capacity, it would be logical to remove one of the machines from the automation system. In order acceptance there are four computers and four personnel, the usage rate is 44.64%. This capacity can be decreased to three not to have excess capacity. In sample acceptance and result approval units, utilization rates are 34.59% and 14.44%. In both processes there is one personnel in each, one single personnel can do both acceptance and approval.

By reason of the poor quality of the barcode labels, more than one label is used for one tube. This situation causes extra cost, waste of both workforce and time. When the labels fall from the tubes, samples are lost because of having no identifier on. Hence laboratory management should also do betterment in the quality of barcode labels and train the personnel on this particular issue.

Another transaction done during transfer of the samples to the laboratory entrance is attaching order papers to the samples. The personnel takes the samples from pneumatic system, detaches the papers and then make the order acceptance. Those papers are not used in that unit, it is just a meaningless action which does not add any value, but takes time. This transaction should be eliminated in order to save time because they are not made use of in any of the stages.

In a widespread manner laboratories and hospitals do jobs which are seriously significant. So, each of the included sub-processes and procedures all have quiet importance in terms of system efficiency, cost and service quality. The whole system is a matter of health; so it is crucial to have the balance among these edges.

5.4. Conclusion

The main aim of the usage of simulation modeling is to evaluate the anticipated behavior and performance of the systems no matter what the application is about. The system may involve distribution center mechanization, material handling, production process automation, storage and control processes. Simulation modeling provides understanding the system operations and the technical capabilities of the design, gives the opportunity to compare the concepts and select the best option. It allows determining the results of the proposed changes on operating procedures, testing and validating the alterations related to the system design. Simulation modeling makes it possible to anticipate the undesirable situations, find solutions with minor changes to those problems and estimate required betterments to the system operating processes. These characteristics of simulation are valid only if the model is built accurately including all the details that are possible of the real system (Banks and Gibson, 1998).

Though simulation is a powerful tool, it may not be a solution for all kinds of system related problems. According to Harrel and Tumay (1995) simulation should mainly point operational sides of systems such as; how, what, where, when the jobs are carried out. Surely all of the system performance issues are not operation related, other than that there exist human and technological issues. Human related issues represent interests, skills, relationships between managers and employees, while technological issues stand for technical requirements, process capability and equipment reliability. By the help of simulation one can see how the system would perform under given human and technological characteristics. The point which meant to be given here is; simulation should not be replaced with analytical thinking, it just helps human to conceptualize complex relations, evaluates different factors which a human mind is not capable of doing.

In this study, a hospital laboratory is analyzed. Work flow of the entire process is illustrated and defined, assumptions are stated, data analysis is done. After establishing simulation model in Arena, output analysis is conducted to determine the warm-up period, number of replications, carry out verification and validation of the model. According to the results of the simulation run, recommendations are given in order to decrease the total time spent in the system and increase patient satisfaction.

The tests of blood, throat cultures and all body fluids are processed in the laboratory. Biochemistry, microbiology, immunology and serology laboratories are all included. However hormone and biochemistry laboratories are embodied in this study since other laboratories have structural differences and are processed separately. This may be regarded as the limitation of this study. As a future research, the laboratory as a whole can be simulated, which case has much more level of complexity and mobility.

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