VIETNAM NATIONAL UNIVERSITY – HOCHIMINH CITY
INTERNATIONAL UNIVERSITY
SCHOOL OF INDUSTRIAL ENGINEERING & MANAGEMENT

APPLICATION OF HEALTHCARE SIMULATION AND OPTIMIZATION FOR DIAGNOSIS PROCESS IN HOSPITAL: A CASE STUDY OF CHO RAY HOSPITAL

Submitted in partial fulfilment of the requirements for the Degree of Bachelor of Engineering in (Industrial and Systems Engineering/ Logistics and Supply Chain Management)

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By
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ABSTRACT

Cho Ray hospital is facing overcrowding of patients in outpatient treatment the patients who come to examine have a high waiting time throughout the week. This causes many problems for patients because they have to spend so much time waiting for a doctor to examine, where for patients a general examination can take a whole day. Faced with the current problem, a discrete event simulation was used to simulate the actual model, thereby looking at the medical examination process, resource allocation and patient flow to find the root cause of this problem. A simulation model is built from actual data in the hospital as well as through research to find out the problems and come up with solutions to reduce waiting time. Besides, the application of operation research also helps to find solutions, by proposing a mixed integer linear programming model, there will be changes in the schedule of doctors which also increase the utilization and reduce the waiting time of patients. In this situation, although it may not be feasible to instantly apply to the actual model, it will be a stepping stone for hospitals to later rely on and can improve in the future.

Keywords: *Cho Ray Hospital, general examination, waiting time, simulation, operation research.*

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CHAPTER 1. INTRODUCTION

This chapter introduces a brief description of the research's background and rationale; next, research problems are specified, which are then directed down to objectives and research methodology. Finally, the scope and limitations are discussed, coming up with the final part which is the research structure.

1.1. Background

a) Vietnam healthcare system:

Healthcare is one of the key objectives of the Vietnamese government. Established in 1945, The Ministry of Health of Vietnam is an agency of the Government, performing the function of State management over the care and protection of people's health, including the fields of preventive medicine, medical examination and treatment, and functional rehabilitation, traditional medicine, medicine for prevention and treatment of human diseases, cosmetics affecting human health, food safety and hygiene and medical equipment. So far, the healthcare network in Vietnam has spread across all 63 provinces and cities with more than 470,000 staff including doctors, pharmacists, physicians and nurses. In addition to providing the best quality of service, the health care system in Viet Nam also offers the opportunity to give medical examinations and treatment to everyone through the issuance of health insurance. By 2018, the number of people enrolled in health insurance has reached 83 million people with a rate of 86.8% with a target of at least 90% by 2020.

	2014	2015	2016	2017	Sơ bộ *Prel.* 2018
Dân số trung bình (Nghìn người) *Average population (Thous. persons)*	90728,9	91709,8	92692,2	93677,6	94666,0
Dân số trung bình dưới 16 tuổi *Average population aged 16 years and below*				23546,4	23817,4
Dân số trung bình dưới 18 tuổi *Average population aged 18 years and below*				26315,6	26550,3
Chỉ số phát triển con người *Human Development Index (HDI)*	0,682	0,688	0,695	0,700	0,706
Tuổi thọ trung bình tính từ lúc sinh (Năm) *Life expectancy at birth (Year)*	73,23	73,31	73,39	73,45	73,49
Số năm đi học bình quân (Năm) *Mean years of schooling (Year)*	8,3	8,38	8,49	8,56	8,64
Số năm đi học kỳ vọng (Năm) *Expected years of schooling (Year)*	11,31	11,37	11,45	11,47	11,54
Thu nhập quốc gia bình quân đầu người (Triệu đồng) *Gross national income per capital (Mill. dongs)*	41,3	43,4	46,6	50,9	55,7
Thu nhập bình quân đầu người một tháng theo giá hiện hành (Nghìn đồng) - *Monthly average income per capita at current prices (Thous. dongs)*	2637		3098		3876
Hệ số bất bình đẳng trong phân phối thu nhập (Hệ số GINI) *Index of income inequality distribution (GINI index)*	0,430		0,431		0,424
Chi tiêu bình quân đầu người một tháng theo giá hiện hành (Nghìn đồng) - *Monthly average expenditure per capita at current prices (Thous. dongs)*	1888		2157		2546
Tỷ lệ hộ nghèo(*) - *Poverty rate(*) (%)*	8,4	7,0	9,2	7,9	6,8
Giường bệnh bình quân 1 vạn dân (Giường)(**) *Patient bed per 10,000 inhabitants (Bed)(**)*	26,3	27,1	27,8	27,1	28,0
Bác sĩ bình quân 1 vạn dân (Người) *Doctor per 10,000 inhabitants (Person)*	7,9	8,0	8,4	7,9	8,6
Tỷ lệ hộ có nguồn nước hợp vệ sinh (%) *Percentage of household having hygienic water (%)*	93,0		93,4		95,7
Tỷ lệ hộ dùng điện sinh hoạt (%) *Percentage of household using electricity (%)*	98,3		98,8		99,0
Tỷ lệ hộ có đồ dùng lâu bền (%) *Percentage of households having durable goods (%)*	99,7		99,7		99,8
Diện tích ở bình quân 1 nhân khẩu (m^2) *Living area per capita (m^2)*	21,4		22,2		23,8

Figure 1.1: Some key social indicators

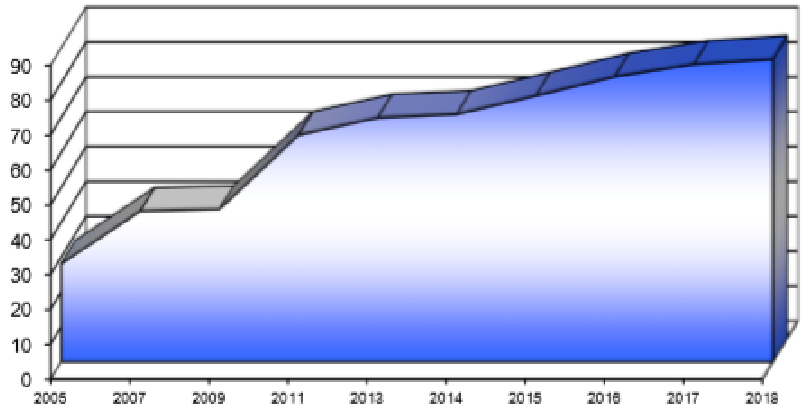

Figure 1.2: Proportion of population participating in health insurance (%)

Only in 2018, the health sector of Vietnam received and treated more than 200,000 times of medical examinations with more than 1,500,000 inpatients and 28,000,000 outpatients. There were 13,547 health facilities with 295,800 patient beds under State management, decreasing by 4.1% against 2017. The number of patient beds under the State management (excluding beds in health centres in communes, wards, offices, and enterprises) per 10,000 inhabitants in 2018 was 28 beds, an increase compared to the 2017 average figure of 27.5 beds.

b) Ho Chi Minh healthcare system

Ho Chi Minh City is the largest city in Vietnam in terms of population and urbanization scale. This is also an economic, political, cultural and educational centre in Vietnam. The city currently has 16 districts, 1 city, 5 districts with a total area of 2,061 km² and the population density are about 8,500,000 people. Ho Chi Minh City is facing the problems of a city with an increasing population, in less than 2 decades, the population has doubled, from 4 million in 1990 to 8 million in 2016. Demand Housing becomes the pressure for development. Every five years, the city's population increases by more than one million people. This leads to a difficult situation for the city, especially in the healthcare sector.

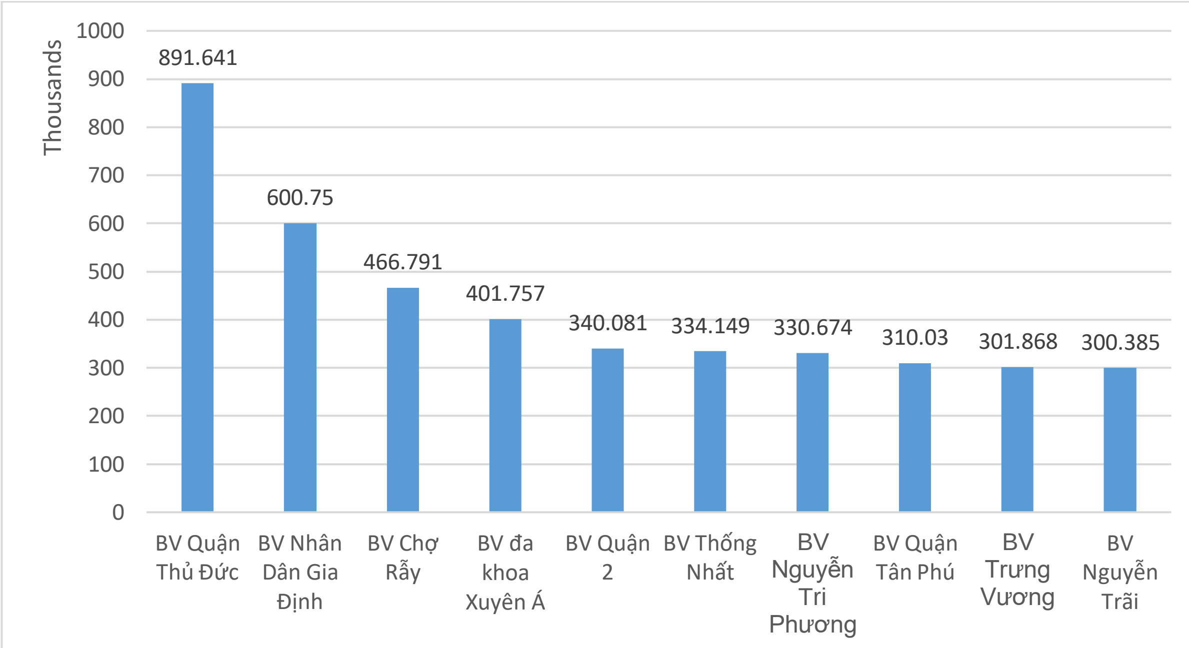

Figure 1.3: The number of patients in Ho Chi Minh City in 6 months

According to Statistics of the Department of Health in 2018, Ho Chi Minh City is the city with the most facilities with 32 provincial hospitals and about 20,000 hospital beds. Ho Chi Minh City also has the highest number of doctors with more than 10,000 doctors, Ho Chi Minh City also has the largest number of doctors with more than 10,000 people, of which the proportion of public doctors accounts for nearly 90%. The rate of doctors in Vietnam is approximately 8 doctors over 10,000 people, this is a fact that the healthcare system is facing a lack of human resources. From there, this leads to the loss of quality of the service, increases the cost of medical examination and treatment as well as creates more pressure on the healthcare system.

c) Cho Ray hospital

Cho Ray Hospital is a national central general hospital, serving the whole South, located in Ho Chi Minh City. This is also one of the largest end-line hospitals in Vietnam. Established in 1900 in Saigon, this is one of the earliest French medical facilities established in Vietnam together with the Saigon Pasteur Institute established in 1891, Nha Trang Pasteur Institute established in 1895.

By 2021, Cho Ray hospital has 5 centres, 11 functional rooms, 5 units, 38 clinical departments and 10 subclinical departments. This is one of the hospitals with the most medical check-ups and is the most accessible place for patients from other provinces to come to Ho Chi Minh city for medical examination and treatment.

Currently, on average, about 30% of patients go to the hospital every day for a health examination. This is a time-consuming process as the patient has to do basic health checks, many tests as well as time to wait for the results. This usually takes 4 hours to 6 hours for each patient and can take up to an entire day.

Health examination has 2 procedures for patients with health insurance and no health insurance. It takes longer for people without health insurance for they have to travel through more locations, therefore, there is no difference in the examination and testing.

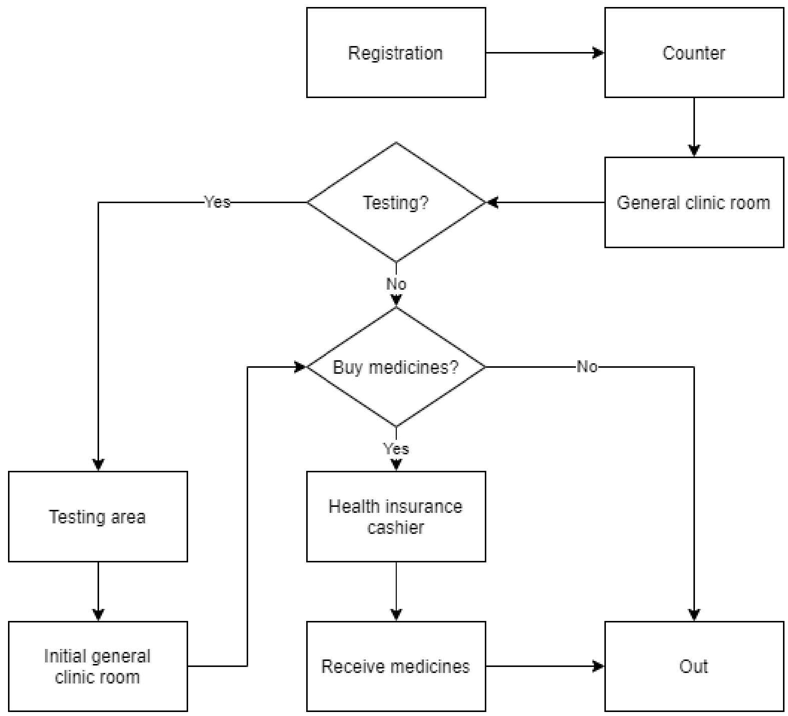

Figure 1.4: General health examination for patients with health insurance

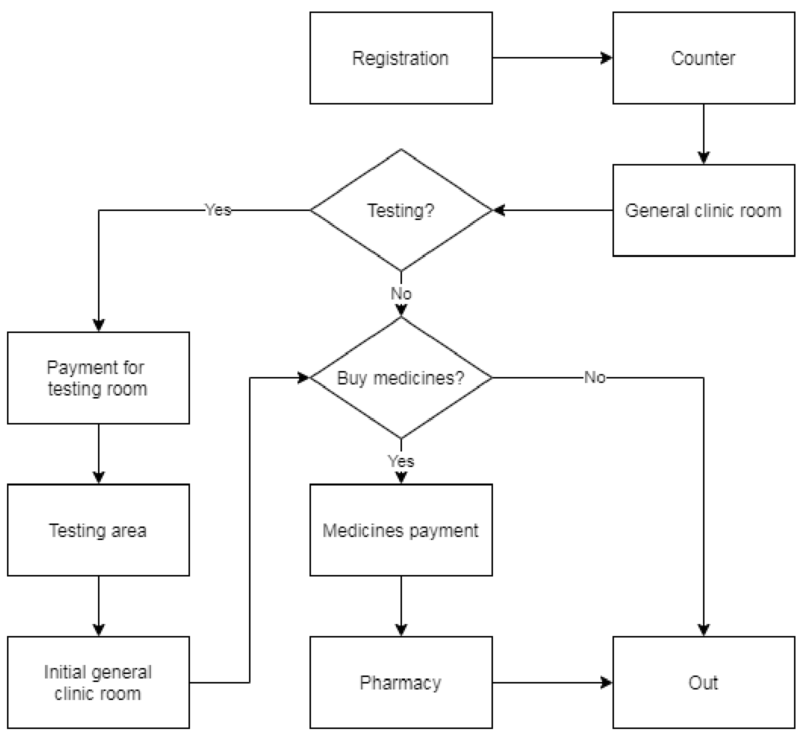

Figure 1.5: General health examination for patients without health insurance

Medical examination procedure:

- First of all, patients will come to the **registration** area to take the number and do the medical register.
- Next patients have to wait for their number in the area receiving illness, the electronic board in each **counter** will show which table patients submit to. The admitting staff will share more information with you and recommend the speciality patients need to see. If the patients do not have health insurance, they will have to pay the medical fees.
- The patients come to the **general clinic room** to see the doctor and to be given descriptions for the testing process.
- The patients without medical insurance have to go to the **payment for the testing counter** to pay the testing fee.
- Both types of patients should go to the **testing area** to be tested base on the descriptions of the doctor and receive the test result later.
- After receiving all the test results, patients will go back to the **initial general clinic room** to see the doctor and to be given the conclusion to buy medicine.
- The patients without medical insurance must go to the **medicines payment cashier** to pay fees and receive medicine at the **pharmacy.**

- The patients with medical insurance have to go to the **health insurance cashier** to be approved the insurance and pays the difference. After that, they can go to the **receive medicines area** to receive the medicine.

1.2. Problem statement

In 2018, Ho Chi Minh City had more than 32 million consultation times and nearly 2 million inpatients, in which the numbers of patients coming from other provinces account for about 40%. With the number of patients increasing over the year but the number of hospitals has not changed, the majority of hospitals in Ho Chi Minh City are facing overcrowding. This results in patients have to spend a lot of time waiting to turn into the clinic.

Through a survey and assessment of service quality in more than 1,300 hospitals, of which nearly 80% of the respondents were satisfied with the quality of medical examination and treatment and more than 20% were not satisfied, focusing on the problem of waiting time. The survey of Tuoi Tre newspaper showed that 58.7% of survey participants said that it takes 2-4 hours for a patient to visit a hospital. Up to 34% of respondents complained that it took 4-8 hours and the rest took more than 8 hours to be examined. This is a problem that the Ministry of Health, as well as hospitals, are always trying to find solutions to.

Representatives of Cho Ray Hospital said that each day the hospital examined and treated nearly 10,000 inpatient and outpatient turns so the overload is almost permanent due to too narrow infrastructure. Not only that, the average medical examination and treatment time of patients here can range from 4 hours to 6 hours and of which most of the time is waiting for tests and testing results, thereby making the patient's medical examination and treatment may last up to a day.

1.3. Objective

The main objective of this paper is to develop simulation models for investigating hospitals, focus on the health examination process. From that to determine the bottleneck and find a solution to reduce patient waiting time. The proposed and modified options will be applied and continually checked to find the best solution for the current model. Through data verification and validation, the most accurate simulation of the process can provide the most reasonable solution and direction for the hospital.

1.4. Scope and limitation

1.4.1. Scope

The study uses the data collected from Cho Ray hospital as input. Building a specific model for a hospital will be time-consuming and very complex, so this thesis only focuses on the medical examination process and improving patient waiting time thereby improving the service quality of the healthcare system.

1.4.2. Limitation

The biggest obstacle is how to get data about the patient's time in each room as well as the examination process because depending on the type of disease there will be different procedures and do not have a specific process. Besides, although the information gathered is from reality, the Covid-19 made it hard to enough sample size. So it is quite small and difficult to give accurate results which are necessary to validate and verify the data to be suitable.

CHAPTER 2. RELATED WORK

2.1. Overview

Medical examination performance criteria according to the Ministry of Health regulation

a. Medical examination time:

- Simple clinical examination: Average examination time is less than 2 hours.
- Clinical examination with:
- One more technique of testing/imaging diagnosis, functional exploration (basic test, the routine x-ray, ultrasound): Average examination time is less than 3 hours.
- Two more additional techniques combining both imaging testing and diagnosis or testing and functional exploration (basic test, the routine x-ray, ultrasound): Average examination time is below 3.5 hours.
- All the additional techniques combining testing, imaging diagnosis and functional exploration (basic test, the routine x-ray, ultrasound, endoscopy): Average examination time is below 4 o'clock.

b. The number of patients:

By 2015, on average, each examination room strives to only examine 50 patients / 8 hours and by 2020 only 35 patients / 8 hours. In the case of a sudden increase in the number of patients due to various reasons, every effort should not exceed 30% of the above target.

2.2. Literature review

M. M. Gunal(2012) indicate that simulation methods have been widely used by healthcare researchers and practitioners[1]. Knowing the hospital is a complex system, this paper is a guide for building hospital simulation models. The first part of the article provides three methods to reduce complexity. First, framing hospital operations, to take the modeller's attention to an area where modelling objectives can be achieved; second, to divide the hospital operations into smaller and manageable parts for modelling and third to aggregate some of the processes in hospitals. The second part of this paper provides the comparison of three simulation models which are Discrete Event Simulation (DES), System Dynamics (SD) and Agent-Based Simulation (BS). From there, we will know the strengths and limitations of the chosen method.

According to E. Hamrock (2013), Discrete Event Simulation (DES) is a data-driven method designed to provide decision-makers with a powerful supplement to change management processes[2]. With the low-cost and lower-risk decisions, DES helps leaders avoid costly, ineffective decisions and allows them to bring out the most effective in improving the system. Applying DES in healthcare commonly focus on (1) patient flow, (2) bed capacity, (3) scheduling staff, (4) patient admission and (5) ancillary resources. This article covers the important steps in using Discrete Event Simulation to examine crowding and patient flow for staffing decision making at an urban academic emergency department. In the conclusion, using Discrete Event Simulation in the healthcare system is highly effective for simulating, finding bottlenecks, suggesting and experimenting with changes.

The Discrete Event Simulation technique is an effective method as well as a hospital aid tool (N. R. Capocci, 2017) [3]. The first part of this paper addresses the theoretical grounding of Operation Research and the basis for simulation. Following, there is the applying of the case study of a healthcare unit by using Arena simulation. By study the current situation of the unit's system and identify the bottleneck, system improvements will be proposed to remove the bottleneck and balance the resource available. This study used a case study of a Polyclinic located in a city of the state of São Paulo and using the help of Arena to evaluate and identify the process and provides many possibilities of changes in the study system. The proposed improvements aim at balancing the occupancy levels of the nurse to test a potential change in the number of attendants. Despite testing and giving the suggestion, this paper runs on only one replication which may decrease the accuracy of the result. This article shows us the steps required in setting up a hospital simulation system, thereby determining the direction for the thesis.

B. Jerbi and H. Kamoun (2009) describes the operation of an emergency department model at a hospital in Tunisia, three departments are used to measure[4]. The model is simulated using Arena simulation software to determine the factor that affects the system. This paper following a chain of steps that provides a clear view of the problem, first the actual model is translated into Arena simulation which already being simplified. The next step is setting up a schedule of doctors, different values of the warm-up length were attempted and a length of 60 minutes of 2 doctors' 8 hours shift was selected, thirty replication were performed with the length of 24 hours a day. In the third step, by using the input analyzer of Arena, this thesis permits the trial of different distributions to all the input data set and chooses the most fittable. After inputting the data to the simulation, different schedules were performed with the change of the starting time of the two doctors' 8-h shift, this aim to find the most optimal solution. However, no single schedule can dominate other schedules on all the performance measures, the goal program was used to choose the best schedule.

A. Jamjoom and his colleagues (2014) used Arena simulation to construct a simulation to improve the quality of the hospital services through rescheduling to reduce waiting time[5].

Serving more than 25,000 patients each year, King Abdulaziz University Hospital has a high patient waiting time. The first step of this paper was to map the process of the OB-Gyn department in the hospital, focus on patients types, scheduling rules and patients flow logic. Based on the flow logic, the next step is to develop a simulation model that reflects real-life situations. The data were collected over one month and used to analyze the accumulated information. This focus on waiting time, arrival pattern, service time to find the result, from there validated the model. After that, using their technique to provide three schedules types with two different percentages of patients arrival to find the best schedule for doctors. After analyzing, the program identified an optimal scenario that reduces the average waiting time by 26% without requiring extra resources.

By examines the design and development of a discrete-event (visual) simulation model which relied on the object-oriented paradigm (OOP) within a physician network, J. R. Swisher (2001) shows a visual simulation environment to help to illustrate the operations of a family practice healthcare clinic[6]. This article also describes in detail the process of data retrieval as well as the importance of simulation model verification, validation, and testing (VV&T). Model verification substantiates that if the model has been properly transformed from the design concept to the simulation, this means that verification is building the model right. On the other hand, model validation means that the model behaves with sufficient accuracy in light of the study's objective. Model testing is the process of revealing errors in a model and may be designed to perform either model verification or model validation. In conclusion, the simulation model allows physicians to perform "what-if" analyses to see the effects of the changes from there to be able to analyze model output statistics.

T. R. Rohleder and his partners (2007) use simulation modelling for redesigning a medical diagnostic laboratory[7]. By applying discrete event simulation modelling into new facility design decisions show a positive change in service times and patient demand. The initial performance of the redesigned facilities was positive; however, complex feedback eventually resulted in unanticipated performance issues inside the service centre framework. It explains how a model of system dynamics may have helped to anticipate these problems with implementation and suggest some ways to boost performance.

Using the Discrete Event Simulation technique, Al-Araidah and his colleagues (2012) aimed to illustrate the usability of DES in modelling and improve the performance in healthcare services[8]. This article can be considered as one of the most specific articles about approaching the hospital problem, simulating the model and suggesting and testing the improvements. The paper not only builds a specific but simple Process Map for the Outpatient Clinic but also translates it through the simulation model, thereby helping to make the solution more convenient. In addition to using the arena simulation for model emulation, the article also uses the arena input analyzer to analyze data and find the best fit distributions. After simulate, results are validated by conducting a t-test with $\alpha = 0.05$, a result of p-value = 0.22 failed to reject the null hypothesis that assumes no difference between the model and the actual clinic performance. This article also gives 4 methods, of which the first three are Controlling Arrival Patterns, Rescheduled resources and a combination of the two above. The last approach is to change the capacity of the hospital, although this will increase the cost or not be applicable because of the clinic's facility limitations but can also be tested for future investment. The findings from cost-free scenarios were comparable to those obtained by increasing ability at the bottleneck operation. In conclusion, even without investing in new resources, patients waiting time can reduce up to 29%.

Summary: I choose paper [8] as my key reference for this paper has a problem that is similar to my thesis, it focuses on the waiting time for patients in the outpatient department and also using Arena simulation as a support tool to simulate the system. This article also details the model design and simulation in Arena, giving the improvement based on the results of the model.

2.3. Design concept consideration

Hospitals are an extremely complex system, so it is necessary to design a model that simulates the work process and changes to find the best option. Many simulation methods can be used for building hospital models, of which there are three most commonly used can be listed out:

- Discrete Event Simulation (DES) is used to model systems based on monitoring entities and changing states dynamically. Each occurrence occurs at a specific point in time and represents a shift in the system's state. Patients, for example, are generated in an "entity creator" module and then transferred to a "processor" module in most DES applications.
- System Dynamics (SD) based on a set of differential equations that tracks instantaneous changes in a dynamic system. This is an approach to understanding the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, table functions and time delay.
- Agent-Based Simulation (ABS) employed to discover systems by using 'deductive' and 'inductive' reasoning. This includes social simulations focused on agent-based

modelling and implemented with artificial agent technology. Agents represent individuals or groups of individuals in these simulations. ABS allows users to investigate various results of phenomena that would otherwise be impossible to observe in real life. ABS can provide us with valuable information on society and the outcomes of social events or phenomena.

CHAPTER 3. METHODOLOGY

3.1. Approach comparison and selection

As introduced before, three simulation methods can be used for building hospital models, each has its advantages, disadvantages and targets different objects. A comparison of the three simulation methods is given in Table 1.

Table 3.1: Comparision of DES, SD and ABS (Gunal, Murat M, 2012)[1]

Discrete Event Simulation (DES)	**System Dynamics (SD)**	**Agent-Based Simulation (ABS)**
Individual focus (Entity)	Group focus (Cohort)	Individual focus (Agent)
Processor defined	Rates are defined	No processor defined
Rules are defined in processors	Rules are defined in different equations	Rules are defined in Agents (autonomy)
Queues exist explicitly	Queues exist explicitly but as levels	Queues exist explicitly
Event derive the simulation	Rates derive the simulation	Local Environment and agents derive the simulation
Mostly stochastic	Mostly deterministic	Mostly deterministic
Discrete-time intervals	Stepped time intervals	Stepped time intervals

In this thesis, to reduce patient waiting time, we will usually focus on the progress of each patient (as an entity), not the group. With a network of processes available, we can easily rely on it to design the desired model. Besides, we can track the movements of individual patients in treatment processes by using the DES model. DES also has visual features which help us understand the system and patient flow much easier. Besides, there are variations and stochastic elements in hospitals, such as random emergency arrivals, length of stay of patients, and clinic appointments. These factors can be easily modelled in DES.

From the above information, the use of DES simulation can be considered as the most optimal solution for the problem to be solved.

For the software, I use ARENA simulation. This is a graphic simulation and animation software created by Rockwell and distributed by Paragon. With the learning by using this software through the course "Simulation Models in Industrial Engineering", this would be a good choice to use in this essay.

3.2. Thesis Frame Work

1. Problem formulation:

This is the initial step to identify the goal of the study and determine what problem need to be solved. When formulating, we will find the most suitable approach and apply it to solve the problem.

2. Setting objectives:

After formulating the problem, the objective of the thesis is indicated. In this step, we will focus on the objectives that we can achieve, the more specific objectives mean clearer expectations. The objective of the article directly affects the determination of how to design the model.

3. Model formulation:

Hospital is a complex system that is hard to simulate even with the most advanced simulation software. So by understanding how the actual system behaves and formulate it into a flow chart, we will reduce the complexity of the system and be able to translate it to the simulation program. When creating a flow chart of the system operates facilitates the understanding of what variables are involved, from there to determine the necessary input data to handle the problem.

4. Model translation:

To solve the system problem, the model must be translated into the simulation software to handle the system. In this step, the flow chart which already determined will be translated into Arena simulation.

5. Verify model:

Model verification substantiates that the model has been properly transformed from the flow chart to an executable program. This process ensures that if the model behaves as intended through animation or debugging.

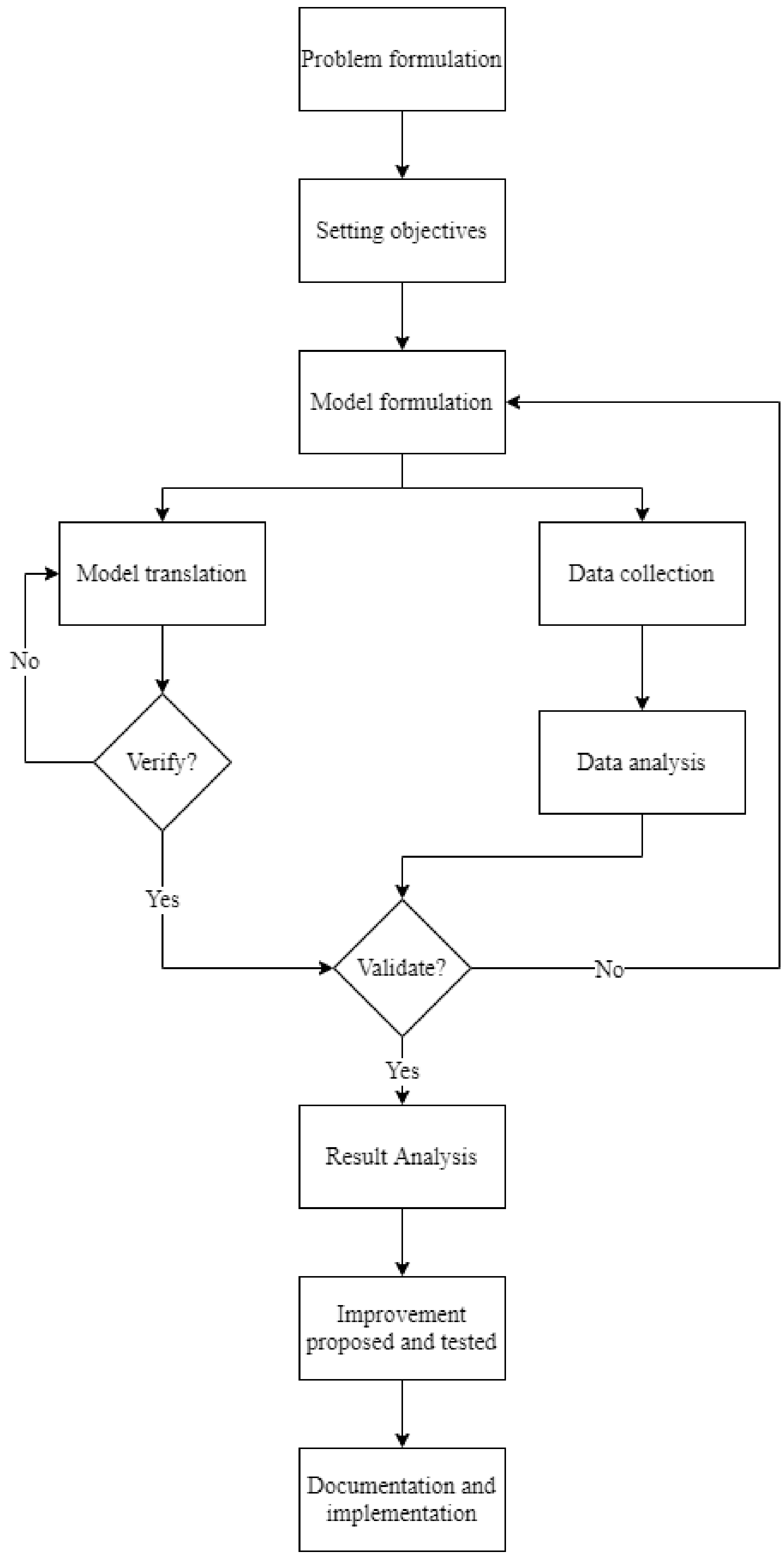

Figure 3.1: Thesis frame work

6. Data collection:

After formulating the model, the set of data to collect is determined.

The input data needed for the hospital simulation system include:

- The number of patients in a day divided by working hours
- The number of doctors and their schedule in each clinic
- Processing time

The data used to check if the simulation model's relevant to the actual model, also be known as output data:

- The waiting time
- The number of patients examines in the clinic
- The number of patients who finished the medical examination process

7. Data analysis:

Collected data can not be taken directly to the model but must be analyzed through supporting software. The data needed to convert to the theoretical distribution before input into the simulation system. Arena input analyzer provides the square error of each distribution which can be used for the data set, thereby assisting in finding the most appropriate distribution data.

8. Validate model:

The main purpose of this step is to check if the simulation model is accurate with the actual model. In this step, the output data will be used to compare if there are similarities with the actual data. The hypothesis test with a significant level at $\alpha = 0.05$ will be used to validate this model.

9. Result analysis:

After validating the model, the output of the simulation will be analyzed to find the bottleneck and the obstacle of the hospital.

10. Improvement proposed and tested:

Based on the result analysis, some improvement is suggested. This might include changing the doctor schedule, increase or decrease the number of doctors in some clinics. These changes will be applied in the simulation model to check if it reaches the objectives of this thesis.

11. Documentation and implementation:

This is the last step which consists of the written report and discusses the implications of the study.

3.3. Model conceptual

a. Patient flow:

The patient will be classified based on health insurance and disease types. As mentioned above, there are 2 types of patients who have insurance and non-insurance, however, there is no difference in medical examination and testing procedures. Depending on each type of disease, the patient will be assigned to a medical clinic room which is suitable, therefore this thesis only focuses on patients who come to the internal general clinic room.

b. The overview process of medical examination:

Either insurance or non-insurance patients will have to register by using registration machines or can be helped by support staff. After that, they will receive a number and wait for a turn in the area receiving illness, here the patient who has health insurance will be assigned to the clinic based on their disease while non-insurance patients must pay the initial medical fee. In the internal general clinic area, patients have to wait for their number before be examined by the doctor. If they do not need to do any tests they can buy medicines as prescribed by the doctor. However, when testing is required, patients with health insurance can go directly to the testing room, while patients without health insurance will have to pay the fee before they can perform the tests procedure. For each type of test, there will be a different waiting time for results, it can be available immediately or after a few hours. When all the results are available the patient can return to the initial clinic to reduced is prioritized seeing the doctor. After receiving a doctor's prescription, the patient can either leave the hospital or go buy medicine. Here, patients with health insurance may have to pay additional costs incurred at the counter for those who have health insurance and receive medicines afterwards. The rest of the patients can buy drugs in the hospital pharmacy.

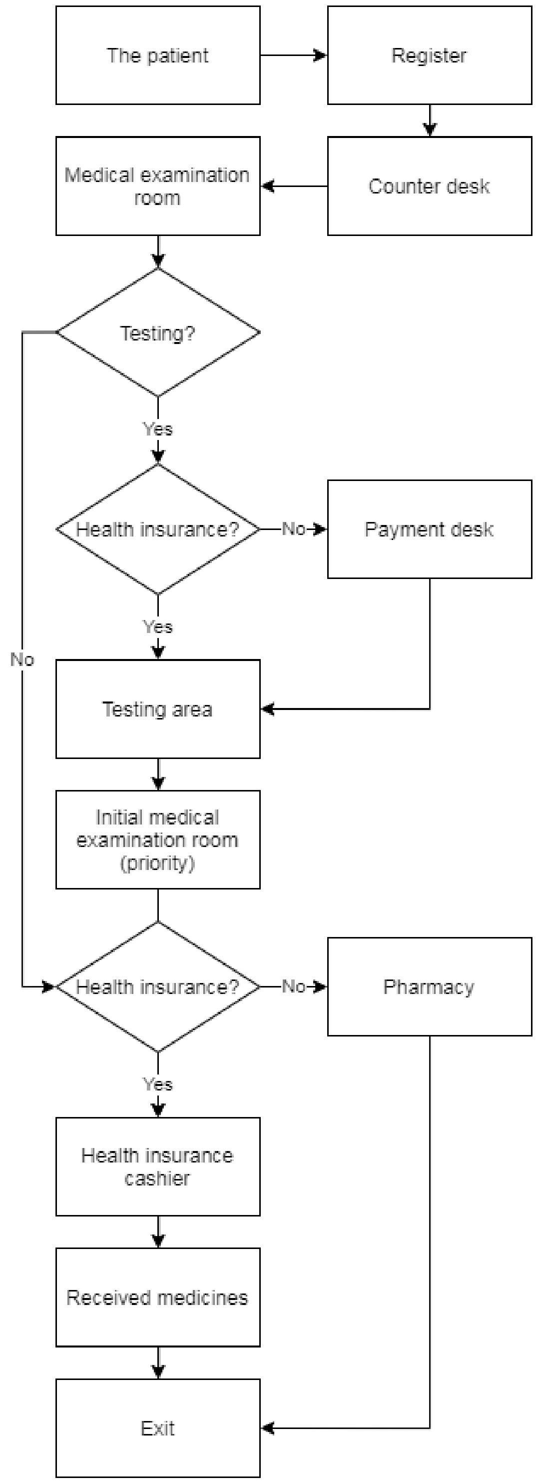

Figure 3.2: Model conceptual for the general medical examination process

c. <u>The process in each area</u>

While the process in receiving area and medicines area is simple and was listed, this part will show only on the medical examination area and testing area.

- **Medical examination area**

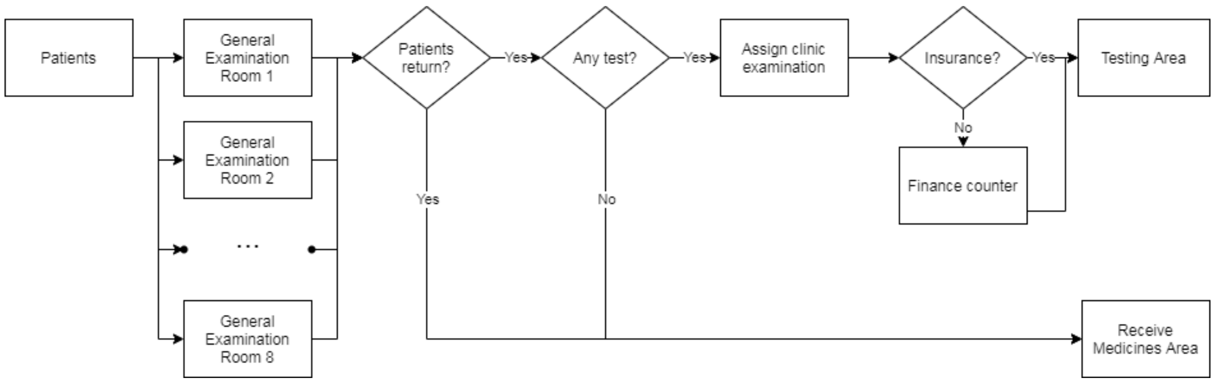

Figure 3.3: Medical examination area conceptual

There are 8 examination rooms, each room has 2 doctors and begins to work from 7:00 am until all the patients are finished. The patient who already did all the tests will be prioritized to meet the doctor in the initial room and come to the receive medicine area later.

If the patients do not need to do any tests they can go to receive medicines area. For those who have to do the test, if they have medical insurance they can go to the testing area, if not they will go to the finance to make a payment before continue.

- **Testing area**

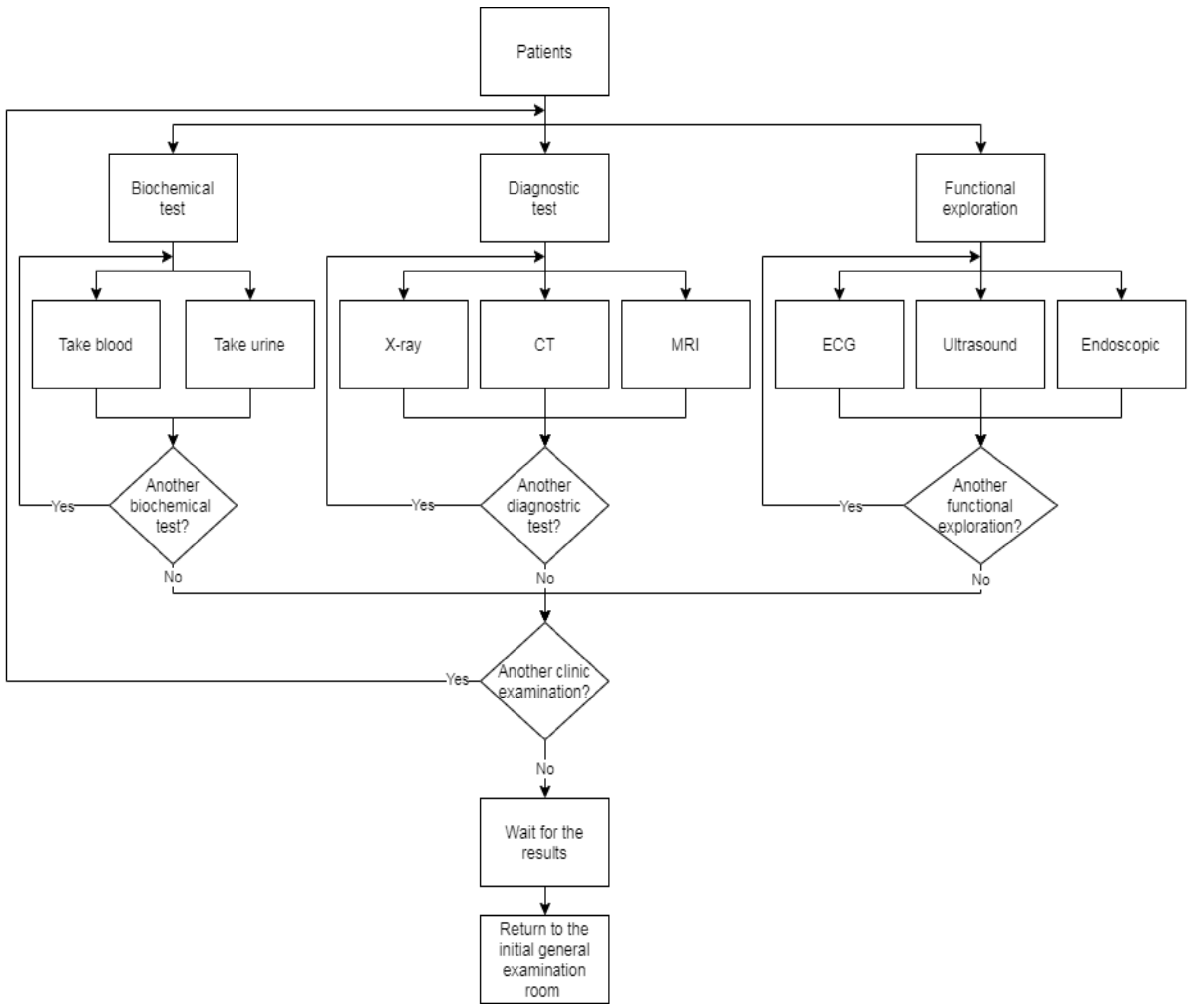

Figure 3.4: Testing area conceptual

Depending on each type of disease, patients will perform the test according to the doctor's request, this may only one test or included multiple tests. Because the types of tests are divided by area, the patient will perform the same type of tests and move to another area later.

The patient after did all the tests required will return to the internal general examination room for advice from the doctor. They will be prioritized and do not have to wait even if there are still patients waiting outside.

3.4. Simulation logic:

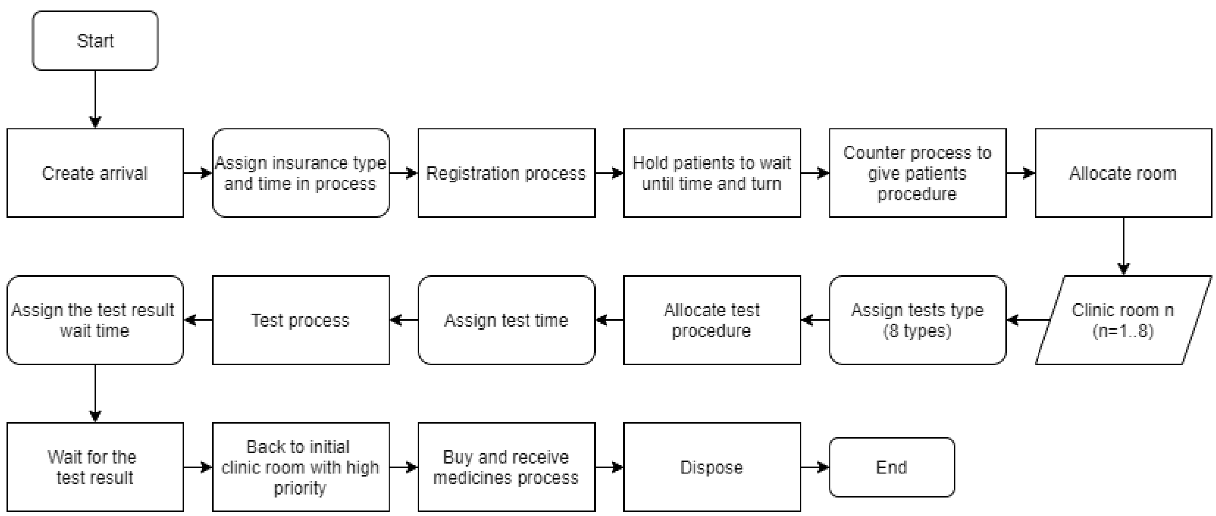

Figure 3.5: Overview of simulation logic

Because the actual process is sometimes extremely complicated, so to be able to design the model in Arena simulation, we need to simplify the problem so that the software can understand it. In addition, discrete event simulation requires that the input model must have logic and follow specific steps. Figure 3.5 shows how a patient moves during a general examination has been simplified and can be relied on to build a complete simulation model in the next chapter.

CHAPTER 4. DATA COLLECTION AND ANALYSIS

4.1. The number of patients who comes to Cho Ray hospital per day

Cho Ray hospital is a central level hospital and has a high number of patients coming from other provinces. Therefore many patients come early to take the number and wait for almost 2 hours for a health examination. Each day there are around 3,000 patients who come to the hospital start at 5:00 to 14:00. However, there is very rare for patients to arrive after noon for they will have to wait a long time to be tested and may have to wait until the next day for the result. The number of patients who come to the hospital is shown in the table below.

Table 4.1: The number of patients divided by time in a day

From	To	Number of patients	Percentage	Cumulative
5:00	6:00	1244	0.476	0.476
6:00	7:00	543	0.208	0.683
7:00	8:00	300	0.115	0.798
8:00	9:00	169	0.065	0.863
9:00	10:00	124	0.047	0.910
10:00	11:00	112	0.043	0.953
11:00	12:00	64	0.024	0.977
12:00	13:00	35	0.013	0.991
13:00	14:00	24	0.009	1.000
Total		2615	1.000	

However, the table includes all the patients who come to examine in all clinics. The number of patients attempts in the general clinic room only account for around 20%. The proportion in each room is shown in APPENDIX C (page G).

If we only focus on the general examination patient, we will have a timetable based on the above ratio.

Table 4.2: The number of patient attempts in the general clinic room

From	To	Number of patients	Cumulative
5:00	6:00	270	0.579
6:00	7:00	118	0.719
7:00	8:00	65	0.800
8:00	9:00	37	0.864
9:00	10:00	27	0.911
10:00	11:00	24	0.953
11:00	12:00	14	0.978
12:00	13:00	8	0.991
13:00	14:00	5	1.000
Total		568	

4.2. The number of function rooms and resources

Cho Ray hospital is comprised of many different faculties and regions, however, this thesis focuses on the areas needed for research. Those areas include:

- Receiving illness
- General clinic
- Biochemical test
- Diagnostic test
- Functional exploration
- Payment and pharmacy

Table 4.3: Receiving illness area resources

Receiving illness	Quantity	Resource name	Resource in each facility
Registration machine	6	Registration machine	1
Registration counter	7	C	1

Table 4.4: General clinic area resources

General clinic	Quantity	Resource name	Resource in each facility
Clinic room 1	1	Clinic 1	1
Clinic room 2	1	Clinic 2	1
Clinic room 3	1	Clinic 3	1
Clinic room 4	1	Clinic 4	1
Clinic room 5	1	Clinic 5	1
Clinic room 6	1	Clinic 6	1
Clinic room 7	1	Clinic 7	1
Clinic room 8	1	Clinic 8	1

Table 4.5: Biochemical test area resources

Biochemical test	Quantity	Resource name	Resource in each facility
Blood	4	takebloodnurse	4
Urine	4	-	-

Table 4.6: Diagnostic test area resources

Diagnostic test	Quantity	Resource name	Resource in each facility
X-ray	8	xraydoctor	1
CT	4	ctdoctor	1
MRI	2	mridoctor	1

Table 4.7: Functional Exploration area resources

Functional Exploration	Quantity	Resource name	Resource in each facility
ECG	1	ecgdoctor	4
Ultrasound	2	ultrasounddoctor	4
Endoscopic	1	endoscopicdoctor	4

Table 4.8: Payment and pharmacy area resources

Payment and pharmacy	Quantity	Resource name	Resource in each facility
Payment for testing	6	testpaymentstaff	1
Insurance payment	4	insurancepayment	1
Medicines receive for an insurance	8	medicineinsurance	1
Noninsurance payment	1	noinsurancepayment	4
Medicines receive for noninsurance	1	medicinenoinsurance	4

4.3. The distance between area

Because the patient will usually do the necessary tests in the same area before going to another area. In which, the travel distance in the same area is not so significant, so we can ignore the travelling distance of patients in clinics in the same area and only pay attention to between areas. In which the blood, urine test rooms and payment are distributed around the hospital for patient convenience, so we can skip the travel to and from these rooms.

Table 4.9: Distance matrix between area(m)

Distance matrix	1	2	3	4	5	6
1	0	10	60	70	30	80
2	10	0	60	50	40	90
3	60	60	0	10	30	20
4	70	50	10	0	40	30
5	30	40	30	40	0	50
6	80	90	20	30	50	0

No.	Area
1	Receiving illness
2	General clinic
3	Diagnostic

4	Functional exploration
5	Pharmacy
6	Insurance medicine

4.4. The ratio of test

There are 8 types of tests, to know which tests the patients are assigned by the doctor. A survey of patients doing a general examination to determine the types of tests or diagnoses the doctor requires. The total test are shown in table below, for the full table of the survey, please go to APPENDIX D (page H).

Table 4.10: Number of tests survey of 100 patients

	Blood	**Urine**	**Xray**	**CT**	**MRI**	**ECG**	**Ultrasound**	**Endoscopic**
Total	79	62	81	15	16	80	19	26

4.5. The processing time analysis

The processing time data are collected by record the time between two patients come in and out, or the time between the change of the number in the electric board in front of the same clinic or function room.

For the clinic that has less than 2 minutes of processing time, we collected 20 data and for those that are higher, there are only 5 data were collected. The data then put into the Input Analyzer to find the most suitable distribution. We changed the distribution for each data set and choose the distribution that had the lowest square error. There are many distributions available, however, we only focused on Uniform distribution, Normal distribution, Triangular distribution. Since there are many analyze need to be checked, there will only 1 processing time distribution test being shown here and the results of others will be shown in APPENDIX E (page K).

Table 4.11: The raw data of taking blood time

No.	Time(sec)	No.	Time(sec)
1	67	11	76
2	52	12	69
3	78	13	82
4	88	14	68
5	65	15	69
6	85	16	66
7	87	17	65
8	63	18	73
9	71	19	63
10	63	20	82

Using Input Analyzer, we have the following results:

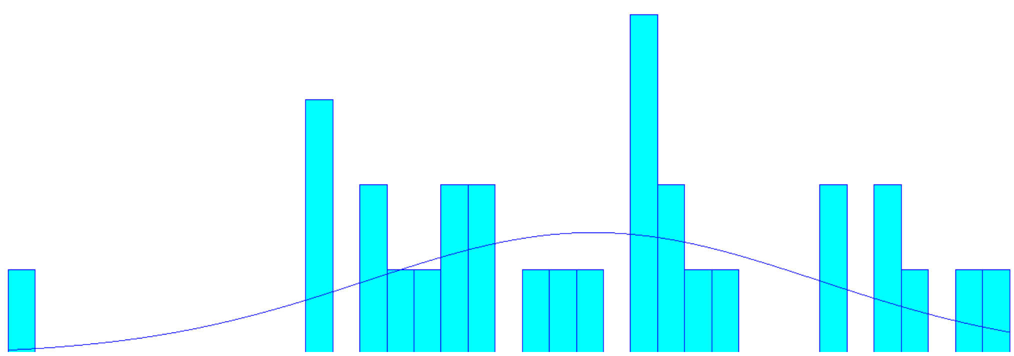

Figure 4.1: Normal distribution of takebloodtime

Distribution: Normal

Expression: NORM(73.1, 8.34)

Square Error: 0.033695

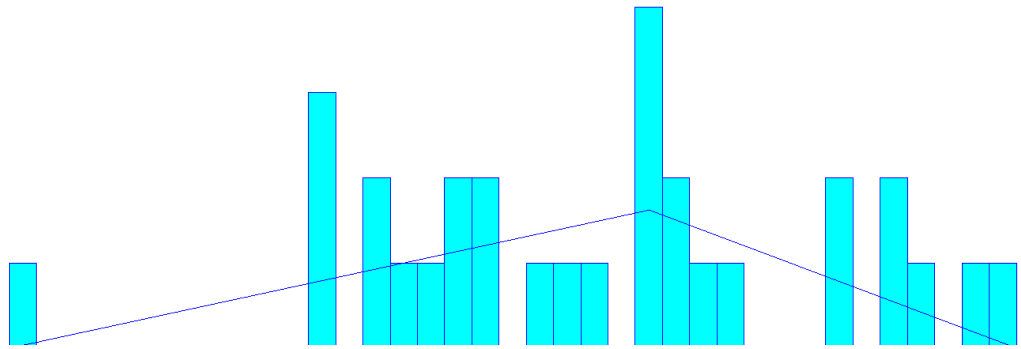

Figure 4.2: Triangular distribution of takebloodtime

Distribution: Triangular

Expression: TRIA(51.5, 75, 88.5)

Square Error: 0.034618

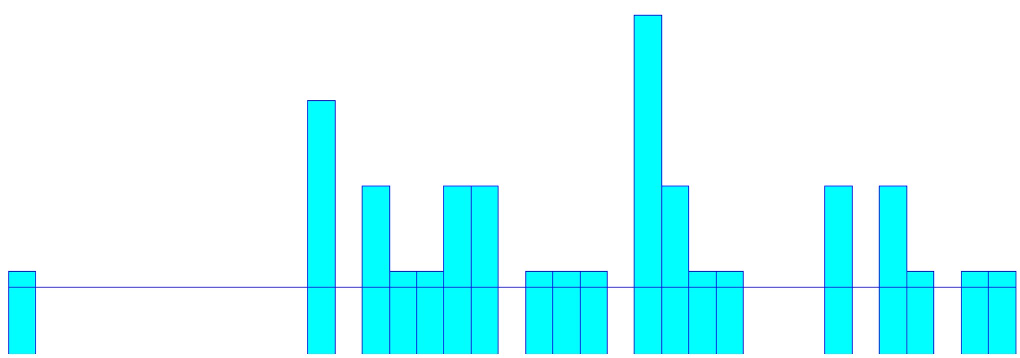

Figure 4.3: Uniform distribution of takebloodtime

Distribution: Uniform

Expression: UNIF(51.5, 88.5)

Square Error: 0.039640

After having 3 results, we need to check the **Square Error(SE)** to find the most fittable distribution. In this case, Normal Distribution with expression NORM(73.1,8.34) has the lowest SE. So this will be the time distribution for takebloodtime to input to Arena. Here we just rounded to the unit seconds for the convenience of tracking, the summary of all the time distributions are shown in the table below:

Table 4.12: Time distribution

time registration	NORM(45,10)
time counter	NORM(29, 4)
clinic time	TRIA(180, 240, 300)
payfortestingtime	NORM(70, 8)
takebloodtime	NORM(73, 8)
takeurinetime	UNIF(129, 172)
xraytime	UNIF(125,233)
Cttime	UNIF(360, 421)
MRItime	UNIF(549, 597)
ECGtime	NORM(150, 16)
Ultrasoundtime	UNIF(182,300)
endoscopictime	UNIF(303, 341)
insurancepaytime	UNIF(63, 112)
noninsurancepaytime	NORM(94, 12)
receiveinsurancetime	NORM(45, 7)
receivenoninsurancetime	NORM(46, 6)

CHAPTER 5. MODELLING

5.1. The simulation model

The modules using for building this simulation are listed and explain below. The explaination is based on "*Simulation with Arena Sixth Edition Manager Arena Simulation Consulting and Support Services Rockwell Automation*. 2015." [12]

- Create module:

This module used to input the patients to the model based on the arrival distribution we already analyze.

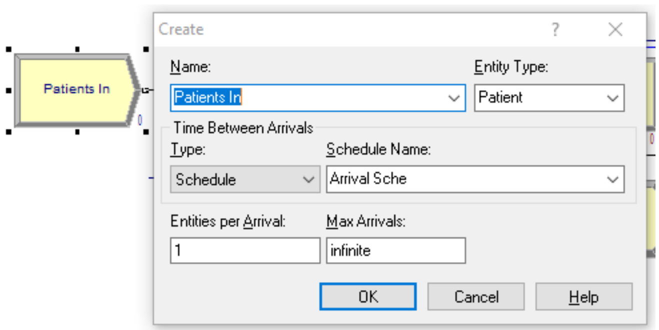

Figure 5.1: Create module

- Dispose module:

This module is used to bring entities in a simulation model to a conclusion. Before an object is disposed of, statistics on it can be registered.

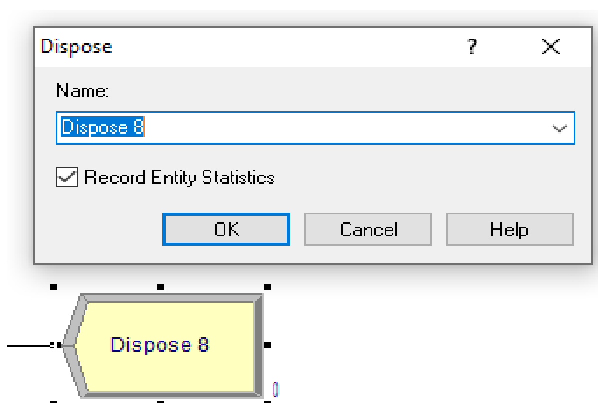

Figure 5.2: Dispose module

- Station module:

The Station module creates a station (or a set of stations) that corresponds to a physical or logical processing site. When you identify a station set in the Station module, you're essentially defining multiple processing locations.

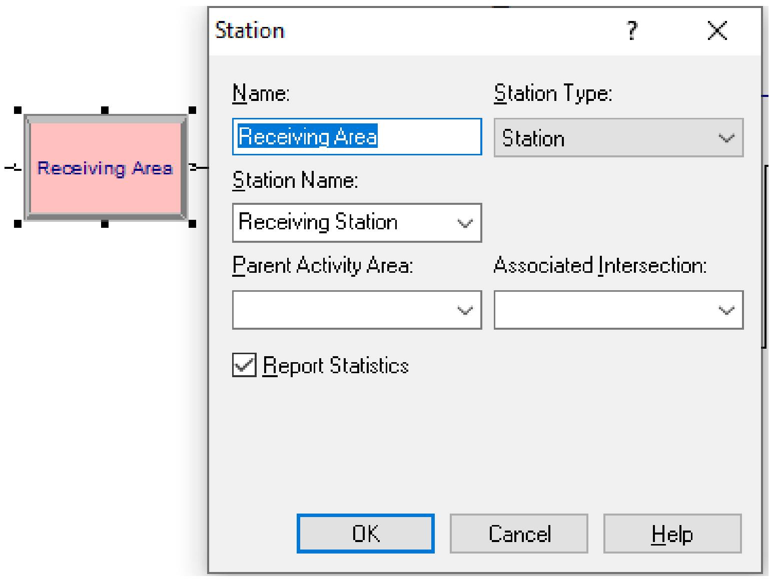

Figure 5.3: Station module

- Route module:

The Route module moves an entity to a specified station or the next station in the entity's given station visitation series. It is possible to set a time limit for transferring to the next station.

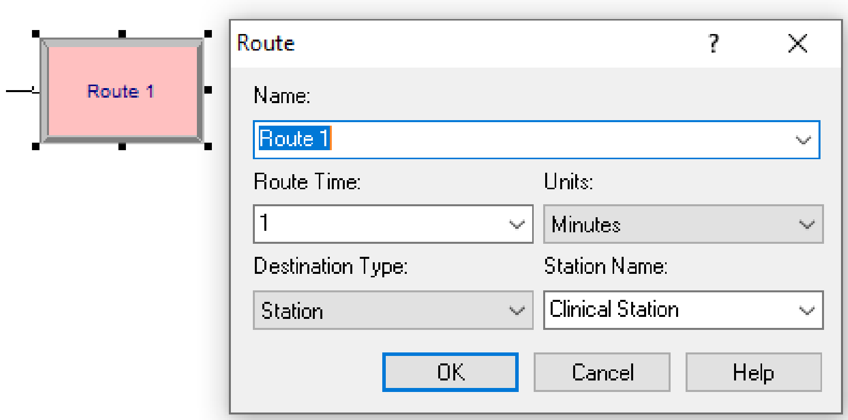

Figure 5.4: Route module

- Assign module:

This module is used to modify variables, entity attributes, entity types, entity images, and other machine variables. A single Assign module can be used to create multiple assignments.

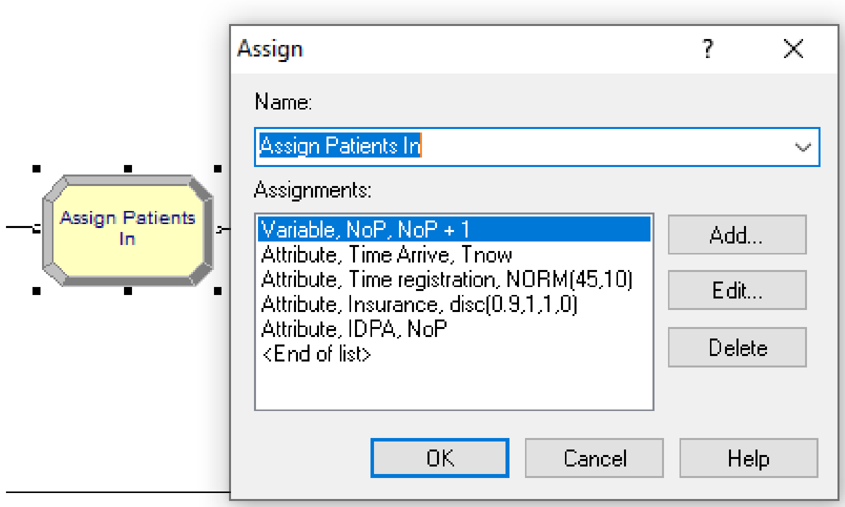

Figure 5.5: Assign module

- Hold module:

This module can queue an individual to wait for a signal, a specified condition to become true (scan), or to be kept indefinitely (to be removed later with the Remove module).

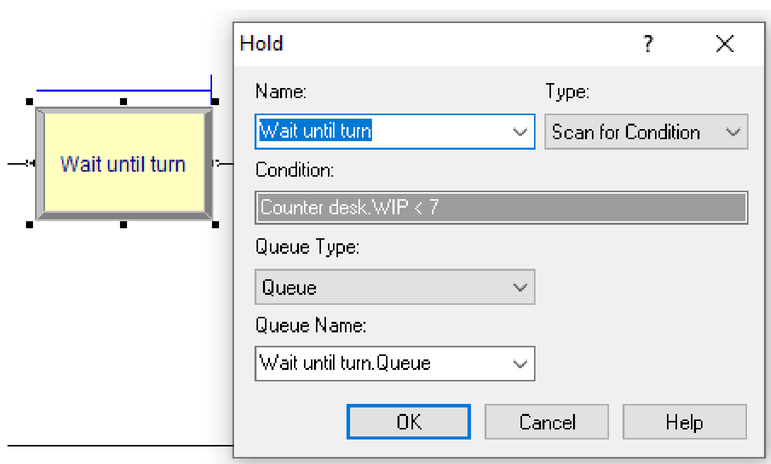

Figure 5.6: Hold module

- **Process module:**

This module is designed to be the simulation's primary processing method. There are options for seizing and releasing resource constraints.

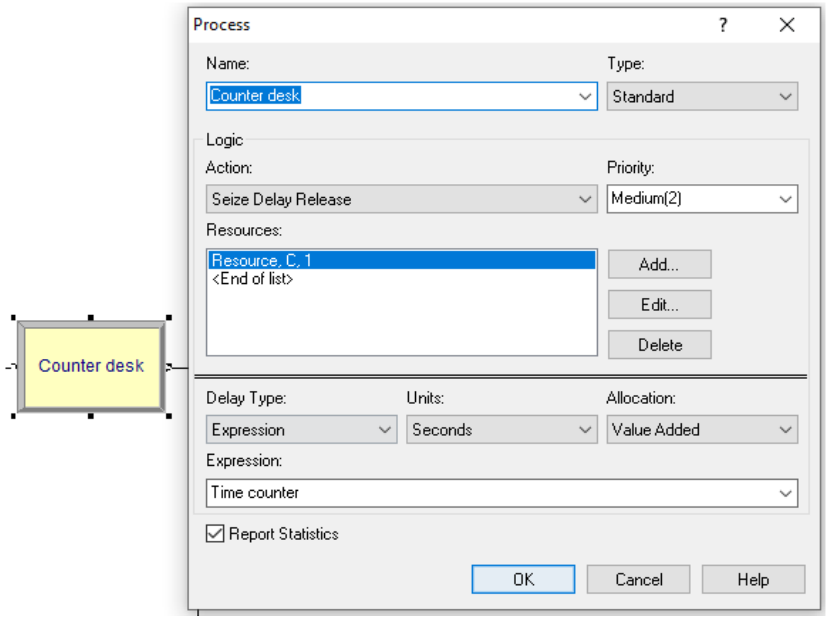

Figure 5.7: Process module

- **Record module:**

This module is used to collect statistics in the simulation model.

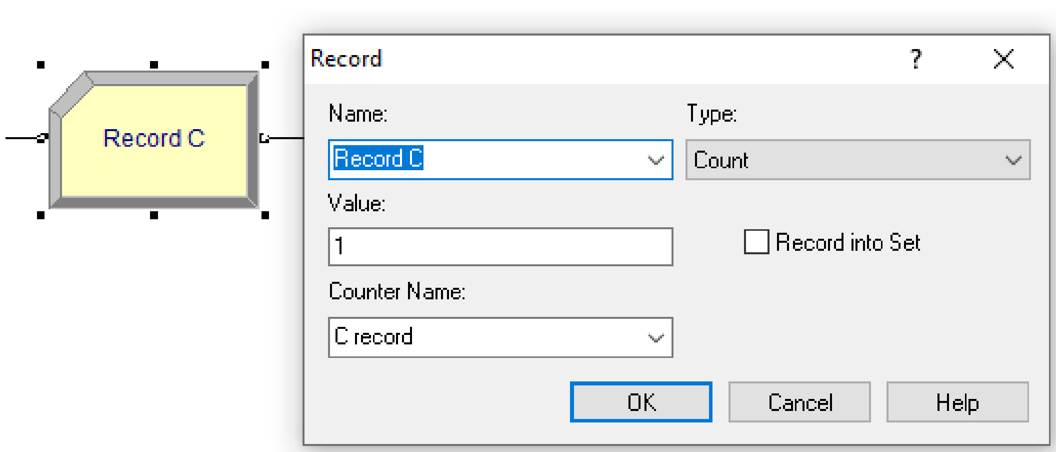

Figure 5.8: Record module

- Decide module:

This module enables the system's decision-making processes. It gives you the ability to make choices based on one or more conditions.

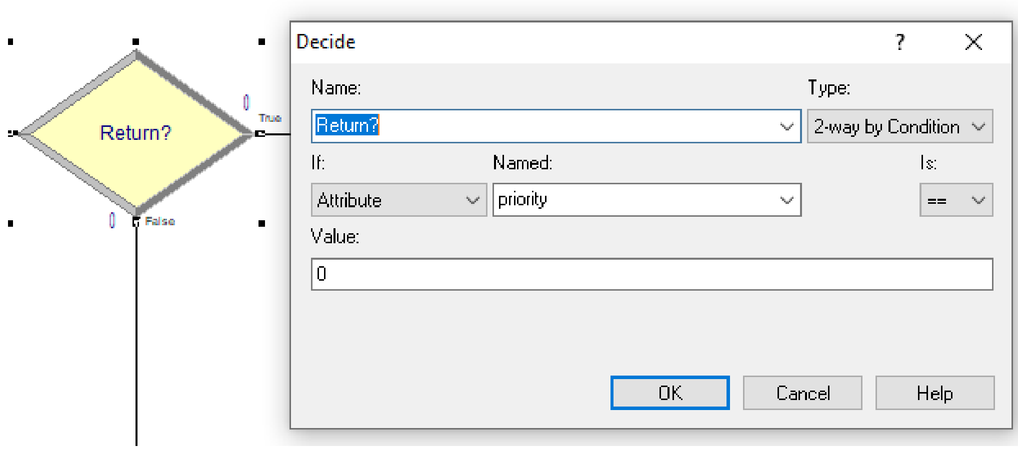

Figure 5.9: Decide module

- Delay module:

The Delay module delays an entity by a specified amount of time.

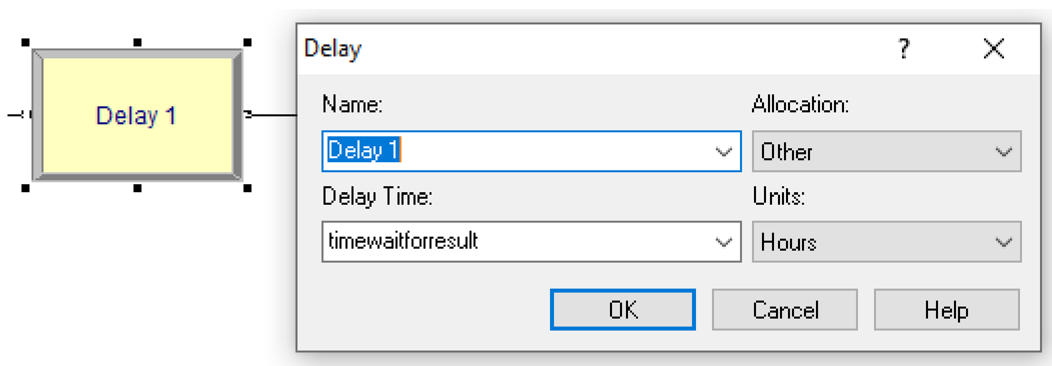

Figure 5.10: Delay module

- PickStation module:

The PickStation module allows an entity to choose a specific station from a list of multiple stations. This module selects a station from a group of stations based on the logic specified in the module. After that, the entity may route, transport, convey, or link to the designated station. If connect is selected as the process, the selected station is given an entity attribute. The station selection process is based on the minimum or maximum value of a variety of system variables and expressions.

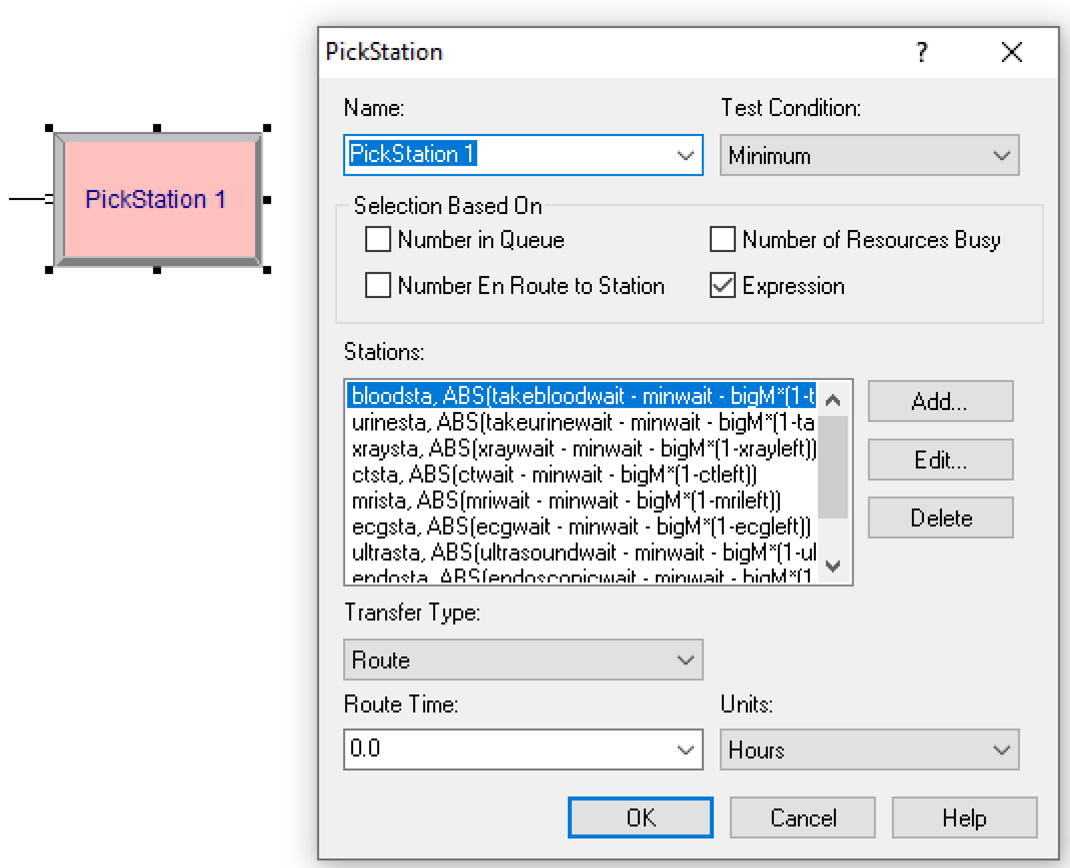

Figure 5.11: PickStation module

- ReadWrite module:

The ReadWrite module reads data from a file or the keyboard and assigns the values to a list of variables or attributes (or other expressions). This module can also write data to an output device like a screen or a file.

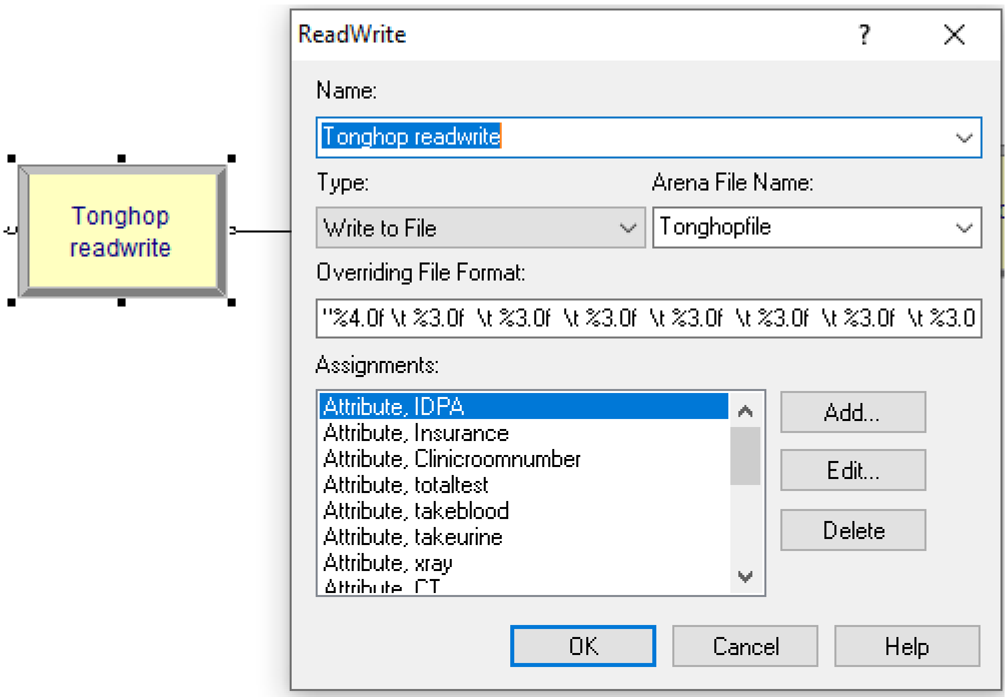

Figure 5.12: ReadWrite module

5.2. Model validation

After building the model in Arena and running the model to get the results, we need to check if the model fits the reality or not. In this section, we will validate the model to make sure that there is a model in the arena that can run like the model in the real world, this also ensures its accuracy.

To compare with the actual model, we will use data that is the number of patients out of a room within 1 hour in 2 days. The building model should be run at 4 different replications to get the required sample. We only focus on the validation of the clinic room and testing room for it is the most important area.

The two-sample t-test is used to determine if the simulation model is equal to the actual model. It is defined as:

$H_0 : \mu_d = 0$

$H_1 : \mu_d \neq 0$

The test statistic is:

$$t_0 = \frac{Y_1 - Y_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$

Where:

Y_1 and Y_2 are the samples means, s_1^2 and s_2^2 are sample variances, N_1 and N_2 are the sizes of each group.

Significant level: 95%

Reject the null hypothesis if $|t_0| > t_{1-0.05/2,n}$

n is degrees of freedom with the formula:

$n = N_1 + N_2 - 2 = 4$

so $t_{1-0.05/2,4} = 2.776$

Table 5.1: The number of patients

	Arena simulation (replication)				**Actual data (day)**	
	1	2	3	4	1	2
Clinic room	27	33	23	25	31	29
Take blood	54	53	56	54	52	55
Take urine	24	24	24	20	24	20
xray	25	18	22	23	21	22
ct	8	10	8	6	9	6
MRI	3	6	6	2	6	4
ECG	21	20	20	20	22	18
Ultrasound	18	18	12	17	15	15
Endo	13	9	10	11	10	13

We calculate the mean, variance and t-test for each function room.

Table 5.2: The t-test of patients in each room

		Mean	Variance	Observation	t0	t	Hypothesized Mean Difference
Clinic room	Arena	27	18.67	4	-1.26	2.776	Do not reject H_0
	Actual	30	2.00	2			
Take blood	Arena	54.25	1.58	4	0.46	2.776	Do not reject H_0
	Actual	53.5	4.50	2			
Take urine	Arena	23	4.00	4	0.44	2.776	Do not reject H_0
	Actual	22	8.00	2			
xray	Arena	22	8.67	4	0.32	2.776	Do not reject H_0
	Actual	21.5	0.50	2			
ct	Arena	8	2.67	4	0.29	2.776	Do not reject H_0
	Actual	7.5	4.50	2			
MRI	Arena	4.25	4.25	4	-0.52	2.776	Do not reject H_0
	Actual	5	2	2			
ECG	Arena	20.25	0.25	4	0.12	2.776	Do not reject H_0
	Actual	20	8	2			
Ultrasound	Arena	16.25	8.25	4	0.87	2.776	Do not reject H_0
	Actual	15	0	2			
Endo	Arena	10.75	2.91666667	4	-0.43	2.776	Do not reject H_0
	Actual	11.5	4.5	2			

After test validation, the result shows that the data collected in Arena simulation are reasonable compared to Actual data.

CHAPTER 6. RESULT ANALYSIS

6.1. The total time of patients

Here, we will look at the patient's total time in the hospital, thereby comparing it with the norms of the Ministry of Health to be able to see the problem more clearly. Because the number of patients entering the hospital each day varies, a 5-day review starting from Monday to Friday is necessary. First, we shall look at the total time including the initial waiting time until the clinic starts working.

Table 6.1: Total time of patients in hospital (including initial waiting time)

	Monday		**Thursday**	
Duration (hour)	**Number of patients**	**Percentage**	**Number of patients**	**Percentage**
<3	31	4.8	25	5.2
3-4	69	10.8	43	8.9
4-5	104	16.3	157	32.6
5-6	417	65.2	255	52.9
>6	19	3.0	2	0.4
Total	640		482	

Table 6.2: Total time of patients in hospital (including initial waiting time)

	Tuesday		Friday	
Duration (hour)	**Number of patients**	**Percentage**	**Number of patients**	**Percentage**
<3	26	5.1	17	3.0
3-4	44	8.6	46	8.1
4-5	138	27.1	91	15.9
5-6	301	59.0	402	70.4
>6	1	0.2	15	2.6
Total	510		571	

Table 6.3: Total time of patients in hospital (including initial waiting time)

	Wednesday	
Duration (hour)	**Number of patients**	**Percentage**
<3	28	5.3
3-4	46	8.6
4-5	76	14.3
5-6	381	71.5
>6	2	0.4
Total	533	

Through the above 5 tables, we can see that most patients spend 5-6 hours in the hospital including waiting time and examination time. And only a small number of patients had a total duration of fewer than 4 hours. This proves that some people, although arriving very early, still have to wait until noon to be examined, which is also a matter of concern of the Ministry of Health.

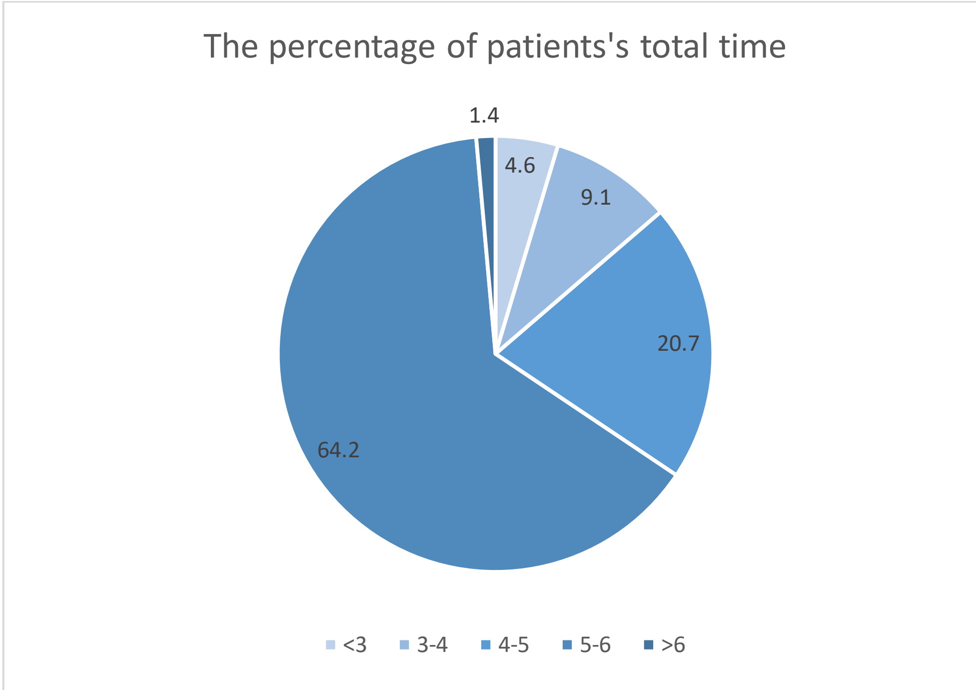

Figure 6.1: The percentage of patients' total time (including initial waiting time)

According to the Ministry of Health regulation which was reminded in chapter 2, medical examination performance criteria are listed below:

- Non para-clinic diagnosis (no test): < 2 hours.

- One type of test (biochemical or diagnostic imaging or functional exploration): < 3 hours.

- Two types of test: < 3.5 hours.

- Three types of tests: < 4 hours.

Here time is counted from the time the patient started going to the clinic, so the initial waiting time will not be counted. We will divide into 4 groups of patients to compare with the standard criteria of the Ministry of Health.

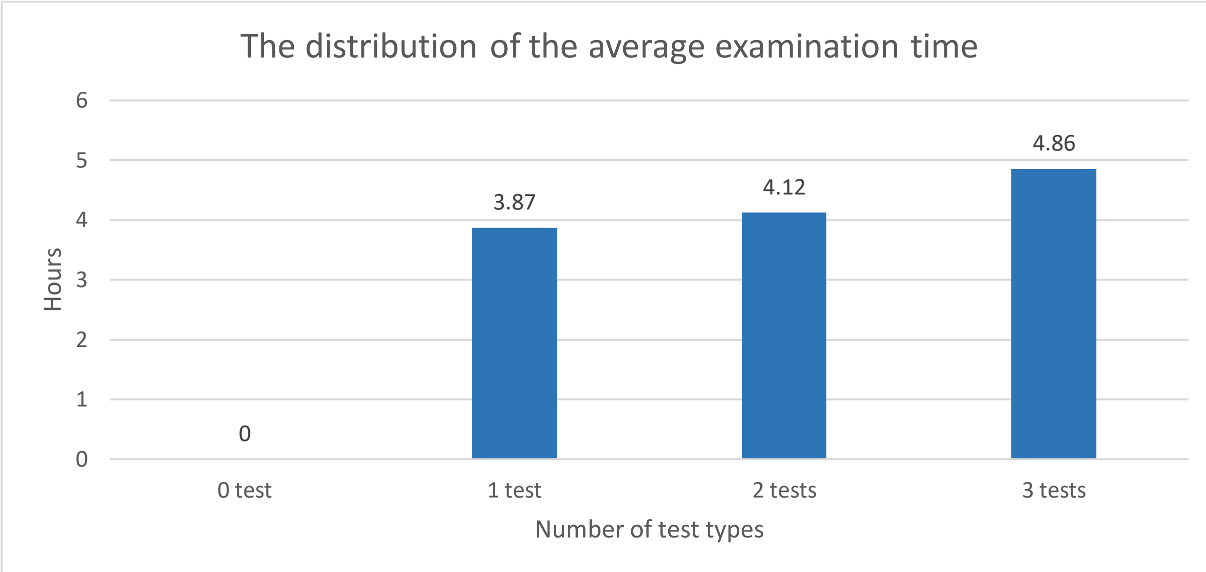

Figure 6.2: The distribution of average examination time in the proportion of test types

While every do at least 1 test type, we can ignore the 0 test criteria.

For patients who attempt 1 test, the average examination time is 3.87 hours which exceeded by nearly 1 hour. Similarly, for 2 tests and 3 tests, the excess time is 0.62 and 0.86, respectively. Compared to the target set by the Ministry of Health, the time for patients to be examined has not met the standards and the patient has to take longer than expected to wait for medical examination. From that, we can see that the hospital is partially overloaded.

According to statistics in 5 days, the patient with the highest total time (only count from the start at the general clinic) was patient number 384 on Friday with 5.7 hours. The table below shows the detailed information about that patient.

Table 6.4: Attributes of patient

Time in	Time out	Time process	Wait for result	Time moving	Waiting time
1.716	8.119	0.333	2	0.044	3.32

We see that patients come to the hospital quite early but leave late, patients also spend a lot of time waiting for the clinics to open.

Table 6.5: Test procedure of the patient

blood	urine	xray	ct
1	1	0	0
mri	**ecg**	**ultrasound**	**endoscopic**
1	1	1	1

Following the table above, this patient has to do 6 tests. The waiting time for the results of taking blood is the highest at 2 hours, so it is equal to the wait for a result time.

6.2. The waiting time of patients

To find out which function rooms are currently overloaded and a bottleneck, the average time a patient needs to wait at each clinic is listed below. With the average waiting time at a clinic being too high, this will increase the average time of patients going to the doctor and put pressure on the doctor as well as on the hospital side.

Reviewing waiting time in function rooms with the goal can help change and find ways to reduce waiting time, or be a premise for direction for other hospitals in the future.

Table 6.6: Waiting time in each function room

		The average waiting time in each clinic(hour)				
No	**Function room**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
1	General clinic 1	1.03	0.93	1.10	1.09	1.19
2	General clinic 2	0.95	0.94	1.18	0.72	0.93
3	General clinic 3	0.92	0.90	0.78	0.82	1.02
4	General clinic 4	0.70	0.77	0.63	0.68	1.08
5	General clinic 5	1.05	0.91	0.97	0.91	1.01
6	General clinic 6	1.13	0.64	0.98	0.85	0.84
7	General clinic 7	0.99	0.92	1.03	0.77	0.89

8	General clinic 8	1.32	1.19	0.77	0.97	1.06
9	Take blood	0.00	0.00	0.00	0.00	0.00
10	X-ray	0.02	0.01	0.03	0.02	0.02
11	CT	0.04	0.02	0.00	0.01	0.06
12	MRI	0.70	0.60	0.38	0.78	0.83
13	ECG	0.00	0.00	0.00	0.00	0.00
14	Ultrasound	0.64	0.52	0.55	0.43	0.68
15	Endoscopic	0.18	0.27	0.20	0.19	0.15

In general, the general clinics usually have an average waiting time of about 1 hour, of which on Monday has general clinic 8 with nearly one and a half hours. This proves that general clinics are facing many problems in dealing with the large medical examination needs of patients. Meanwhile, in a testing room such as blood draw, xray, ct, ecg and endoscopic, patients do not need to wait too long. In the mri room, the waiting time ranges from 20 minutes to 50 minutes from Monday to Friday, and in ultrasound, the average time is 30 minutes on weekdays.

6.3. The number of patients in each clinic

The Ministry of Health requires that each room strives to only examine 35 patients / 8 hours in 2020, in the case of a sudden increase in the number of patients due to various reasons, every effort should not exceed 30% of the above target. Statistics on the number of patients entering each clinic room through 5 days of the week are considered to check the standardization of each room. Here, we cannot rely on this data to evaluate the quality of the test room, because not only patients from the general clinic come here but also from many other clinics. Therefore, it will not be possible to use the indicator in the general room to calculate the whole. we already know the hospital is overcrowded, so the criteria to evaluate will be 46 patients (30% more than the original criteria)

Table 6.7: The number of patientss in each clinic in Monday

Monday				
No	**The function room**	**Patients**	**Situation**	**Difference to criteria(%)**
1	General clinic 1	77	Overload	167
2	General clinic 2	79	Overload	172
3	General clinic 3	72	Overload	157
4	General clinic 4	69	Overload	150
5	General clinic 5	82	Overload	178
6	General clinic 6	89	Overload	193
7	General clinic 7	80	Overload	174
8	General clinic 8	92	Overload	200

Table 6.8: The number of patientss in each clinic in Tuesday

Tuesday				
No	**The function room**	**Patients**	**Situation**	**Difference to criteria(%)**
1	General clinic 1	64	Overload	139
2	General clinic 2	64	Overload	139
3	General clinic 3	66	Overload	143
4	General clinic 4	56	Overload	122
5	General clinic 5	60	Overload	130
6	General clinic 6	58	Overload	126
7	General clinic 7	65	Overload	141
8	General clinic 8	77	Overload	167

Table 6.9: The number of patientss in each clinic in Wednesday

Wednesday				
No	**The function room**	**Patients**	**Situation**	**Difference to criteria(%)**
1	General clinic 1	72	Overload	157
2	General clinic 2	84	Overload	183
3	General clinic 3	58	Overload	126
4	General clinic 4	61	Overload	133
5	General clinic 5	62	Overload	135
6	General clinic 6	64	Overload	139
7	General clinic 7	71	Overload	154
8	General clinic 8	61	Overload	133

Table 6.10: The number of patientss in each clinic in Thursday

Thursday				
No	**The function room**	**Patients**	**Situation**	**Difference to criteria(%)**
1	General clinic 1	66	Overload	143
2	General clinic 2	60	Overload	130
3	General clinic 3	62	Overload	135
4	General clinic 4	54	Overload	117
5	General clinic 5	64	Overload	139
6	General clinic 6	55	Overload	120
7	General clinic 7	55	Overload	120
8	General clinic 8	66	Overload	143

Table 6.11: The number of patientss in each clinic in Friday

Friday				
No	**The function room**	**Patients**	**Situation**	**Difference to criteria(%)**
1	General clinic 1	77	Overload	167
2	General clinic 2	66	Overload	143
3	General clinic 3	76	Overload	165
4	General clinic 4	74	Overload	161
5	General clinic 5	71	Overload	154
6	General clinic 6	66	Overload	143
7	General clinic 7	66	Overload	143
8	General clinic 8	75	Overload	163

Through the above situation, the general clinics are always overloaded, twice as much as the target set by the Ministry of Health for 2020. From there, we can see that the hospital is overloaded by the number of patients as well as the hospital's facilities.

6.4. Utilization of staff

Table 6.12: The utilization of each clinic room from Monday to Friday and the average

Instantaneous Utilization						
Resouce	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Average**
Clinic 1	0.57	0.42	0.52	0.53	0.6	0.528
Clinic 2	0.57	0.43	0.61	0.47	0.5	0.516
Clinic 3	0.53	0.44	0.42	0.48	0.58	0.49
Clinic 4	0.5	0.38	0.45	0.43	0.58	0.468
Clinic 5	0.62	0.41	0.45	0.52	0.55	0.51
Clinic 6	0.65	0.39	0.47	0.43	0.52	0.492
Clinic 7	0.59	0.44	0.53	0.44	0.5	0.5
Clinic 8	0.68	0.52	0.45	0.54	0.58	0.554
takeblood	0.08	0.06	0.07	0.07	0.08	0.072
xray	0.34	0.24	0.3	0.28	0.32	0.296
ct	0.3	0.19	0.19	0.22	0.31	0.242
mri	0.6	0.4	0.38	0.5	0.57	0.49
ecg	0.2	0.13	0.2	0.18	0.2	0.182
ultrasound	0.52	0.4	0.42	0.41	0.49	0.448
endoscopic	0.41	0.34	0.36	0.32	0.38	0.362

Although as stated above, the waiting time in general clinics is usually quite high, here utilization is just average (about 0.5 per room during weekdays). This shows that patients are only concentrated in some of the most time frames and then quite a few people come to the clinic. So it is possible to consider testing and make suggestions based on this model to increase utilization as well as reduce waiting time. Besides, if it is possible to control the flow of patients entering the clinic, it will also help reduce the waiting time significantly. In this article, although the utilization of the test rooms has been mentioned, it cannot be based on that assessment because of not only the general patient but also many other patients.

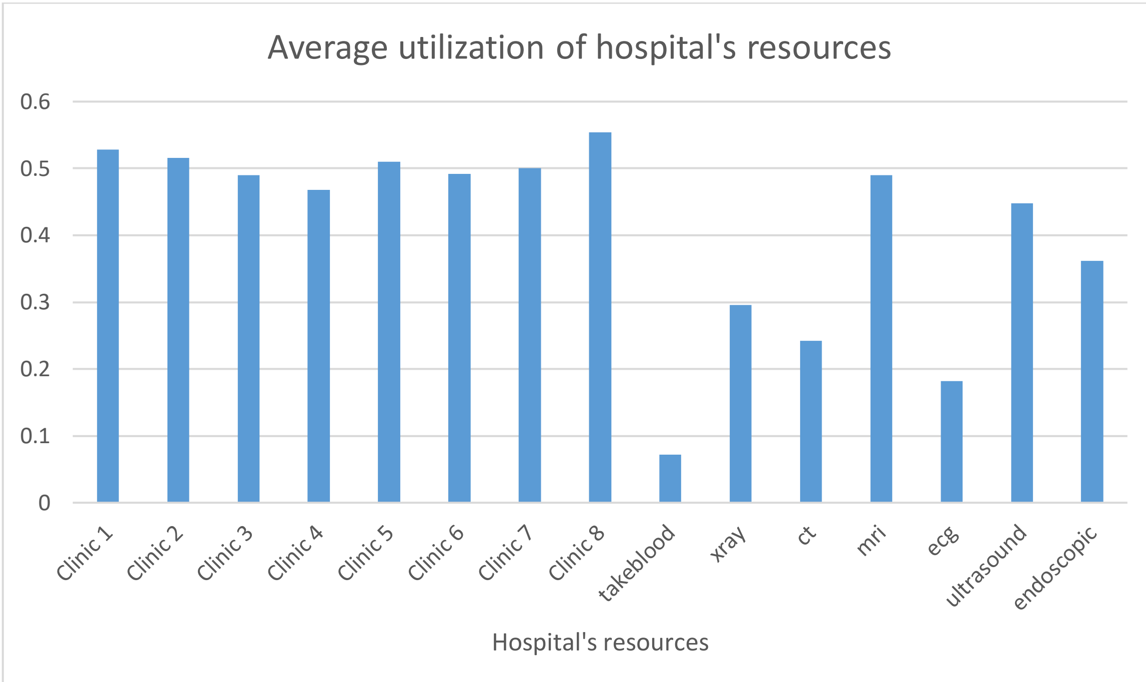

Figure 6.3: Average utilization of each resource in Cho Ray hospital

CHAPTER 7. IMPROVEMENT SUGGESTION

From the simulation model, we evaluate the model to find the bottleneck and offer solutions that can help in improving patient waiting time or in terms of staffing in the hospital.

Suggestion 1: Changing returning examination time to reduce waiting time

First, as noted above, we will see that in general clinics, the number of patients in the time frames is often uneven and disparate.

Table 7.1: Number of patients entering the clinic in time frames

Time		General Clinic room							
From	**To**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
7:00	8:00	30	30	30	30	30	31	31	30
8:00	9:00	29	30	30	23	28	30	29	30
9:00	10:00	10	9	4	5	17	16	9	26
10:00	11:00	31	31	31	32	29	31	31	30
11:00	12:00	29	29	29	30	29	29	29	30
12:00	13:00	18	16	10	4	23	26	20	30
13:00	14:00	2	2	0	2	0	2	1	3
14:00	15:00	9	7	6	5	6	9	11	0
15:00	16:00	2	2	0	1	0	2	1	7
16:00	17:00	0	0	0	0	0	0	0	0
	Total	160	156	140	132	162	176	162	186

Although there is a priority for patients who have completed the test and return to the clinic, those patients also have to wait until 10:00 am to meet the doctor again. Although this reduces waiting times for early arrivals, it will significantly increase the number of patients seen after 10 hours. Meanwhile, from about 9 am to 10 am, the number of patients examined in the rooms is not too much. Therefore, the postponement of the examination time for patients who have completed the test can be changed to earlier. Here, we will try to move up at 4 different time frames, 9:00 am, 9:15 am, 9:30 am and 9:45 am.

Here we will consider the factor of average waiting time, maximum waiting time in general clinics and of patients; besides, the factor of total time in hospital should also be mentioned.

Table 7.2: Comparing the differences when changing returning examination time

Time	**The average waiting time in the clinic**	**The maximum waiting time in the clinic**	**Average waiting time of patients**	**Maximum waiting time of patient**	**Average total time**
9:00	0.823	2.238	2.636	4.830	4.333
9:15	0.781	2.571	2.800	5.163	4.460
9:30	0.782	2.253	2.983	5.325	4.614
9:45	0.722	1.999	3.144	5.528	4.475
Initial time	0.738	2.108	3.322	5.781	4.934

Based on the tables above, when starting the return time at 9:45, we will have the lowest average of average waiting time and the maximum waiting time, but the total waiting time is quite high at more than 3 hours. Meanwhile, if the start time is at 9:00, although there is an increase in average and maximum waiting time in the clinic, it is not high when it is only 10 minutes more. But it resulted in a significant reduction in the average waiting time for all patients, about 45 minutes compared to starting at 10:00 and 30 minutes compared to 9:45. this also resulted in the lowest average total time for the patients, only about 4:20 compared to the initial 5:00.

Suggestion 2: Changing returning examination time and changing doctor's schedule to increase utilization

As mentioned above, the early hours have a high number of patients and the later hours are quite small, so the total utilization of doctors is not high, only about 0.5 to 0.7 in general clinics. Here, the rearrangement of the number of doctors based on the number of patients who need to be seen in each time frame can be considered necessary to reduce costs for the hospital.

Combined with the proven suggestion 1 above, here we use the mathematical model programming model to try to improve the above problem. The main goal here is still to reduce the patient's waiting time based on the number of patients that need to be examined, having obtained data from the previous simulation runs.

Here, we will have 8 rooms corresponding to the 8 general clinic rooms above and the number of doctors will be 16 equal to the original. There are 10-time frames, each frame corresponds to 1 hour lasting from 7 am to 5 pm. The number of patients visiting the clinic in each time frame is shown in the table below.

Table 7.3: Number of patients need to be examined in each clinic room

Room / Time	1	2	3	4	5	6	7	8
1	64	63	55	46	61	70	59	77
2	3	3	7	7	10	3	7	4
3	27	30	29	27	30	31	25	30
4	33	29	28	29	31	31	34	31
5	9	14	11	2	13	11	11	12
6	6	8	4	3	7	2	3	3
7	4	7	2	2	14	12	4	13
8	2	2	1	1	5	2	0	12
9	0	2	1	1	2	0	1	0
10	0	0	0	0	1	0	0	0

MODEL

1.1. Index

I	index of rooms
J	index of times
MaxDoc	maximum number of Doctor

1.2. Parameter

pat_{ij}	number of patients visiting Room **i** in each Time **j**

1.3. Decision Variable

x_{ij}	x=1 if there are still unexamined patients
P_{ij}	number of patients examined in Room **i** at Time **j**
D_{ij}	number of patients need to be examined in Room **i** at Time **j**
$doctor_{ij}$	number of doctors in Room **i** at Time **j**
dif_{ij}	number of unexamined patients in Room **i** at Time **j**

1.4. Objective function

$$\text{Minimize} \qquad \textstyle\sum_i \sum_j dif_{ij}$$

Here, the goal is still to minimize the number of patients having to wait through each time frame which also reduces the patient's waiting time.

1.5. Constraints

Constraint 1:

number of unexamined patients = number of patients need to be examined

- number of patients examined

$dif_{ij} = D_{ij} - P_{ij}$ $\forall$ i,j

Constraint 2:

number of patients need to be examined = number of patients visiting

+ number of unexamined patients in the previous time frame

$D_{ij} = pat_{ij} + dif_{i,j-1}$ $\forall$ i,j

Constraint 3:

The average time of a patient's examination is 4 minutes (1/15 hours), so the number of patients examined in a 1-hour room must not exceed the number of doctors in that time frame.

$P_{ij} * (1/15) \leq doctor_{ij}$ $\forall$ i,j

Constraint 4:

To optimize doctors utilization, the total patient visit time must be greater than 0.6 times the total working time.

$\sum_j P_{ij} * \left(\frac{1}{15}\right) \geq 0.6 * \sum_j \text{doctor}_{ij}$ $\forall$ i

Constraint 5:

The total number of doctors in a time frame must not exceed the maximum number of doctor.

$\sum_i \text{doctor}_{ij} \leq \text{MaxDoc}$ $\forall$ j

Constraint 6:

If there is a patient to be examined, then x_{ij} must be equal to 1.

$D_{ij} \leq x_{ij} * 1000000$ $\forall$ i,j

Constraint 7:

If there are patients to be examined, there must be at least 1 doctor in that room.

$\text{doctor}_{ij} \geq x_{ij}$ $\forall$ i,j

Constraint 8:

All doctors work from the first time frame and work continuously until the break, no additional doctors are allowed in the later hours.

$\text{doctor}_{ij} \leq \text{doctor}_{i,j-1}$ $\forall$ i,j

Constraint 9:

In each room, all patients must be examined.

$\sum_j P_{ij} = \sum_j pat_{ij}$ $\forall$ i

RESULT

The optional solution given by cplex is 464, which means 464 times that the patient was not examined in the required time frame and moved to another time frame.

Table 7.4: Number of doctors in each room at each time frame

Room \ Time	1	2	3	4	5	6	7	8	9	10
1	2	2	2	2	2	1	1	1	1	1
2	2	2	2	2	2	1	1	1	1	1
3	2	2	2	2	2	2	1	1	1	1
4	2	2	2	2	1	1	1	1	1	1
5	2	2	2	2	2	1	1	1	1	1

6	2	2	2	2	2	1	1	1	1	1
7	2	2	2	2	2	1	1	1	1	1
8	2	2	2	2	2	1	1	1	1	1

According to the decision variable doctor, we can find the optimal doctor for each time frame in each room. By changing the schedule in Arena simulation base on the new schedule given, we can find if the new schedule is worth considering.

Comparing the current situation result and the improved result in simulation.

Table 7.5: Comparing the current and the improved schedule for the doctor

	Current	Improved	Difference(%)
Utilization			
Clinic room 1	0.57	0.71	**125**
Clinic room 2	0.57	0.74	**130**
Clinic room 3	0.53	0.61	**115**
Clinic room 4	0.5	0.6	**120**
Clinic room 5	0.62	0.82	**132**
Clinic room 6	0.65	0.8	**123**
Clinic room 7	0.59	0.72	**122**
Clinic room 8	0.68	0.9	**132**
Time			
Average waiting time	3.33	2.71	**81**
Average total time	4.94	4.39	**89**

With the change in doctor's work schedules, utilization in the rooms is improved from 20% to 30%. The following hours are reduced in resources to ensure doctors are more productive. Moreover, average waiting time decreased by nearly 20%, from 3.33 hours to 2.71 hours and total time reduced by 11% from almost 5 hours to 4.4 hours.

Suggestion 3: Increasing resources and changing returning examination time to reduce patients waiting time

Although this will help reduce the patient's waiting time, it is not feasible because the part of recruiting more doctors means expanding more clinics, while the hospital now also has physical problems. Besides, this can be considered as an idea so that later hospital models can be applied to avoid overcrowding like now.

Here we will test 2 cases:

- Case 1: increase by 25% to a total of 20 doctors

For clinics with increased resources, we will increase the rate of assigning patients to that clinic, to reduce the number of patients in the remaining clinic. From 12.5% for each room to 15% for a room with 3 doctors and 10% for a room with only 2 doctors.

- Case 2: increase by 50% to a total of 24 doctors (The rate in each clinic will be the same at 12.5%)

Case 1:

By changing the rate of assigned patients, the number of patients visiting the clinic in each time frame is changed.

Table 7.6: Number of patients need to be examined in each clinic room

Time \ Room	1	2	3	4	5	6	7	8
1	79	78	71	65	53	47	51	52
2	2	3	10	6	11	2	1	6
3	44	43	39	44	21	25	28	29
4	35	42	26	30	32	25	24	31
5	15	10	20	10	15	9	4	9
6	9	9	8	4	4	7	3	6
7	5	4	2	2	4	3	1	4
8	2	3	2	0	1	0	0	1
9	1	0	0	1	1	0	0	0
10	0	0	0	0	0	0	0	0

Room 1, room 2, room 3 and room 4 will have a maximum of 3 doctors while the others only have 2.

The optimal solution reduces to 263, which is nearly 2 times lower than the initial solution.

The new schedule based on cplex will be applied to Arena simulation to check if the result is better.

Table 7.7: Number of doctors in each room at each time frame

Room \ Time	1	2	3	4	5	6	7	8	9	10
1	3	3	3	3	1	1	1	1	1	1
2	3	3	3	3	1	1	1	1	1	1
3	3	3	3	2	2	1	1	1	1	1
4	3	3	3	2	1	1	1	1	1	1
5	2	2	2	2	2	1	1	1	1	1
6	2	2	2	1	1	1	1	1	1	1
7	2	2	1	1	1	1	1	1	1	1
8	2	2	2	2	1	1	1	1	1	1

Table 7.8: Comparing the old and case 1 schedule for the doctor

	Current	Case 1	Difference(%)
Utilization			
Clinic room 1	0.57	0.77	**135**
Clinic room 2	0.57	0.74	**130**
Clinic room 3	0.53	0.69	**130**
Clinic room 4	0.5	0.69	**138**
Clinic room 5	0.62	0.69	**111**
Clinic room 6	0.65	0.62	95
Clinic room 7	0.59	0.69	**117**
Clinic room 8	0.68	0.65	96
Time			
Average waiting time	3.33	2.74	**82**
Average total time	4.94	4.17	**84**

With the increase of resources, change the examination time, and apply the above schedule, except in room numbers 6 and 8 where the resource is increased in the early hours with a decrease in utilization, in the remaining rooms. increase from 10% to 35%. Most significantly, the waiting time was reduced by nearly 20% and the total time was reduced by 16%.

Case 2:

In this case, all the rooms will have a maximum of 3 doctors. Because the rate of assigning patients is not changed, so we can apply the initial number of patients visiting the clinic in each time frame.

Table 7.9: Number of patients need to be examined in each clinic room

Room / Time	1	2	3	4	5	6	7	8
1	64	63	55	46	61	70	59	77
2	3	3	7	7	10	3	7	4
3	27	30	29	27	30	31	25	30
4	33	29	28	29	31	31	34	31
5	9	14	11	2	13	11	11	12
6	6	8	4	3	7	2	3	3
7	4	7	2	2	14	12	4	13
8	2	2	1	1	5	2	0	12
9	0	2	1	1	2	0	1	0
10	0	0	0	0	1	0	0	0

The optional solution continues to reduce to only 194, which is only 2.4 times slower than the initial solution and only 1.3 times slower than the case 1 solution. The new schedule will be list below.

Table 7.10: Number of doctors in each room at each time frame

Time / Room	1	2	3	4	5	6	7	8	9	10
1	3	2	2	2	1	1	1	1	1	1
2	3	2	2	2	1	1	1	1	1	1
3	3	2	2	2	1	1	1	1	1	1
4	3	2	1	1	1	1	1	1	1	1
5	3	3	3	3	1	1	1	1	1	1
6	3	3	3	3	1	1	1	1	1	1
7	3	2	2	2	1	1	1	1	1	1
8	3	3	3	3	1	1	1	1	1	1

Here because the effect of case 1 has been proved and compared to the actual model, so instead of continuing to compare case 2 with the actual model, we will compare with case 1 to determine if case 2 is better than case 1.

Table 7.11: Comparing case 1 and case 2 schedules for the doctor

	Case 1	Case 2	Difference(%)
Utilization			
Clinic room 1	0.76	0.685	90
Clinic room 2	0.68	0.67	99
Clinic room 3	0.8	0.69	86
Clinic room 4	0.66	0.79	**120**
Clinic room 5	0.67	0.46	69
Clinic room 6	0.5	0.55	**110**
Clinic room 7	0.52	0.74	**142**
Clinic room 8	0.6	0.56	93
Time			
Average waiting time	2.65	2.47	**93**
Average total time	4.17	4.05	**97**

From the comparison table, we can see that it is not necessary to increase all rooms by 1 doctor, although reducing the number of patients waiting, in some rooms, it is only really needed in the first time frame where there are the most patients. The next time frames only need a maximum of 2 or 1 doctors, so this option is not feasible.

CHAPTER 8. CONCLUSION AND RECOMMENDATION

8.1. Conclusion

This study presents a scientific method to approach the general medical examination process at Cho Ray hospital using simulation, which was successful in creating a model that can describe the status of the actual system and finding the shortcomings for it.

In this study, the combination of skills learned through subjects such as simulation model design, scheduling, and operation research has been used to create a model that is comparable to the actual model and used to improve utilization of general examination clinic and propose methods to improve patient waiting time.

Therefore, simulation is considered as a safe and economical solution to find bottlenecks as well as provide solutions for not only hospitals but also many other areas such as inventory or production. The use of simulation helps testing and evaluation to find problems without affecting the actual model. In addition, the combination with operation research also helps to provide a solution that is considered suitable for the model. After applying to have some changes, the adjustment will be applied to the simulation model to test and verify the effectiveness.

8.2. Recommendation

Hospitals can use the collected data such as examination time, waiting time, the number of patients, etc. to make suggestions to improve the quality of medical examination and treatment. Based on these data, the hospital can make some adjustments to the examination time for patients who have completed the test, as well as set the maximum time and priority for patients who have waited too long. . Besides, the adjustment of personnel to increase utilization may not be necessary for the current model, but can be used to review the effectiveness of doctors in clinics.

8.3. Economic factors

Using simulation models helps engineers to evaluate the hospital, besides providing methods to support as well as help the hospital plan to use or buy more equipment. This also helps reduce waiting times for patients, thereby attracting more patients to visit. If used effectively, this method will help hospitals have more costs to consider adding medical machines and subclinical equipment.

8.4. Social factors

When using simulation, engineers will easily approach the problem, thereby reducing the time needed to continuously collect actual data. This will help the hospital save time in assessing the actual situation, thereby providing the fastest and most appropriate solution. Besides, it also helps to find out the number of doctors and nurses needed to best serve patients.

8.5. Environmental factors

Applying simulations helps the hospital predict the amount of equipment needed for the patient, thereby calculating the most effective use of the current equipment. Besides, it also avoids the waste of abandoned subclinical equipment and at the same time contributes to calculating the amount of medical waste needed for treatment.

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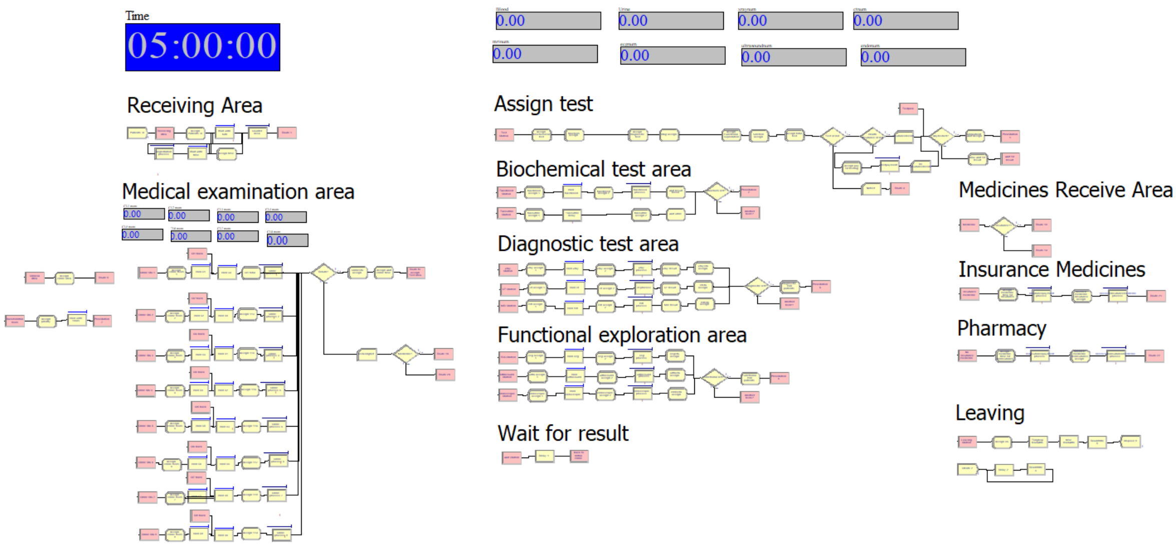
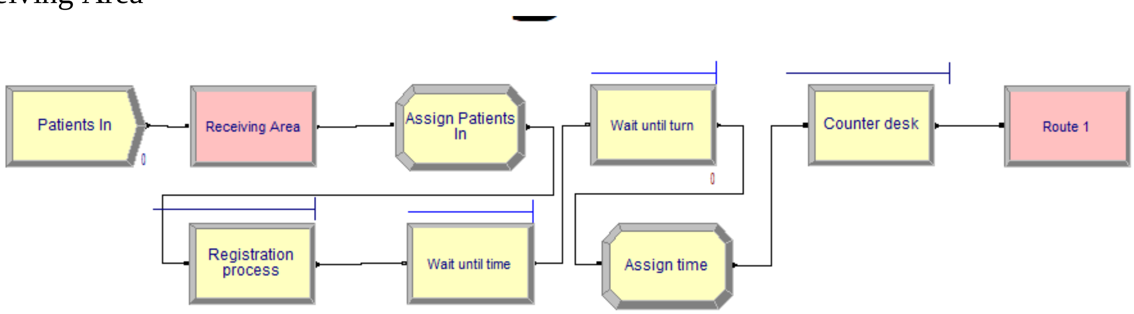
APPENDICES

APPENDIX A: Picture of the model in arena simulation

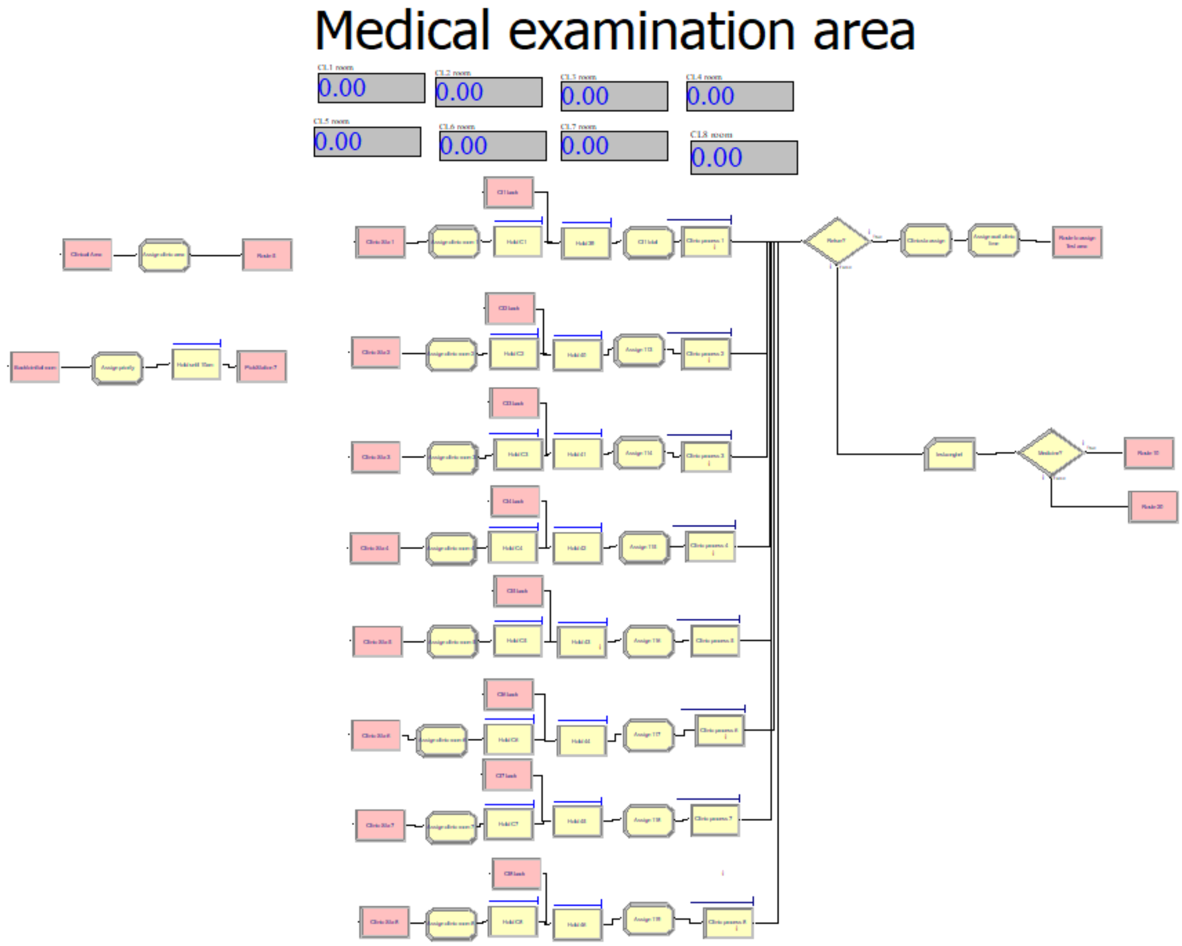
Overall the model



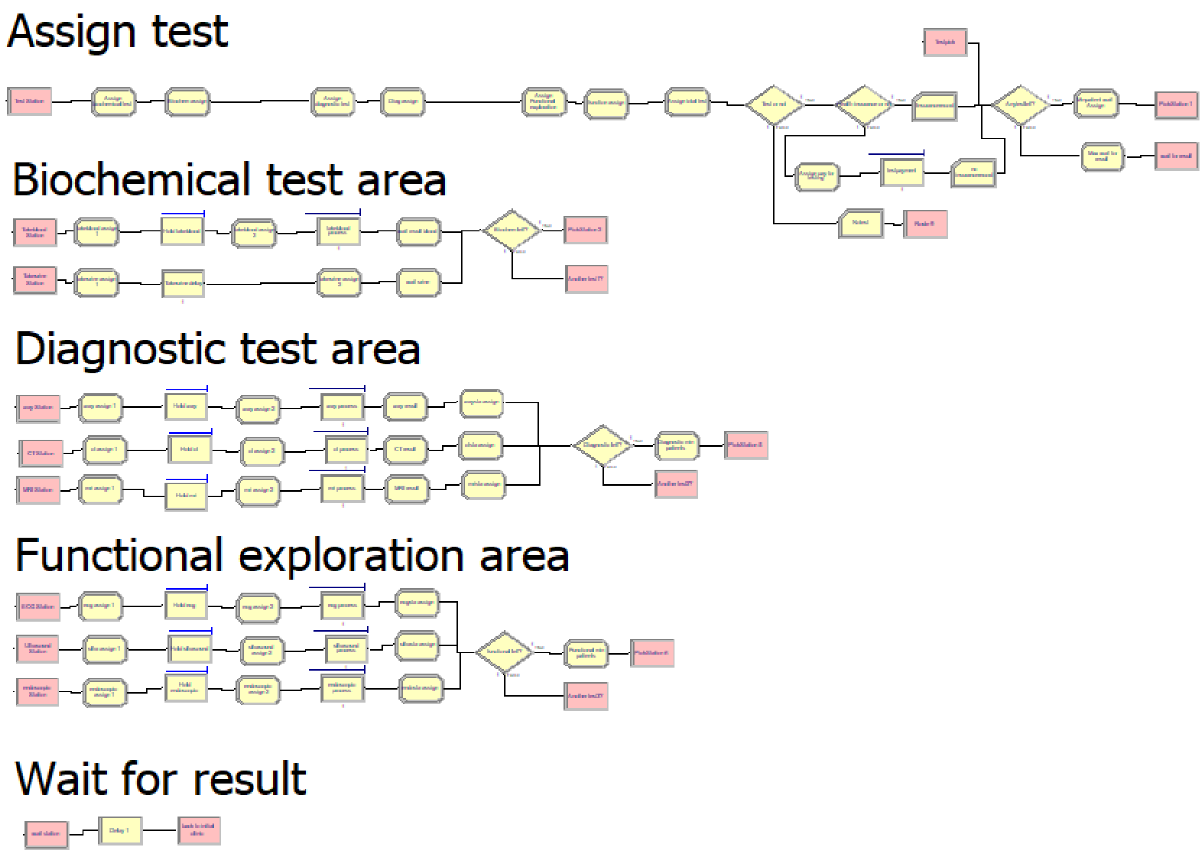
Receiving Area



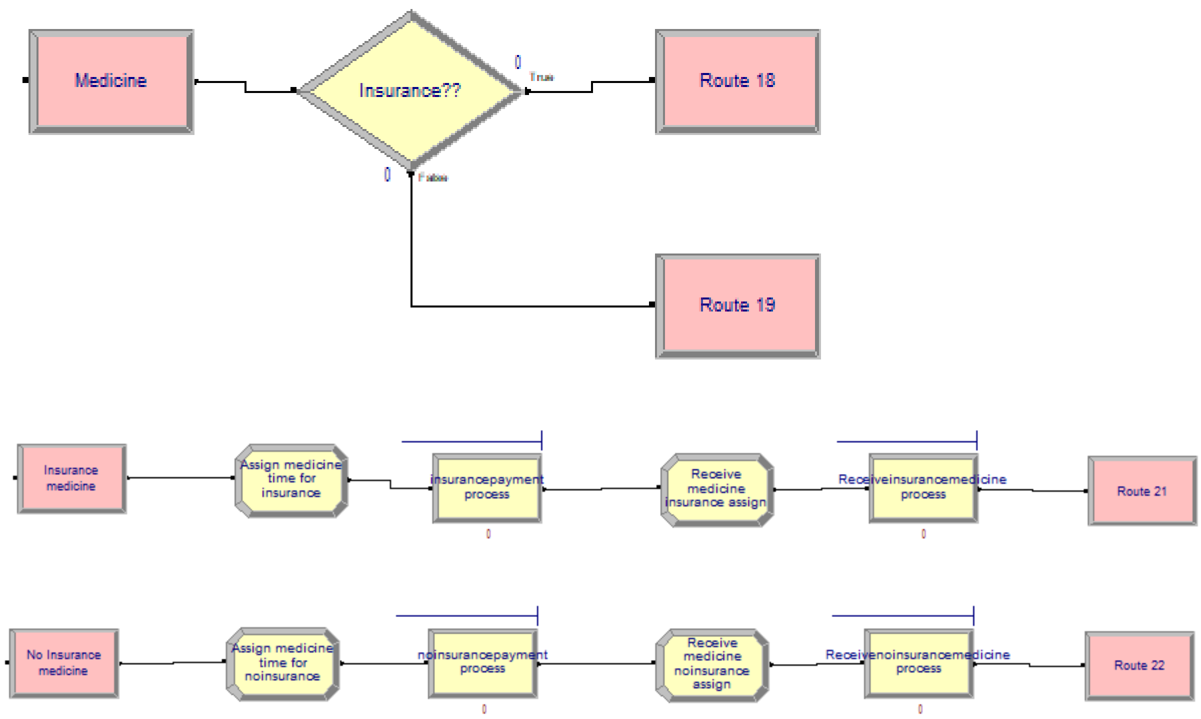
Medical Examination Area



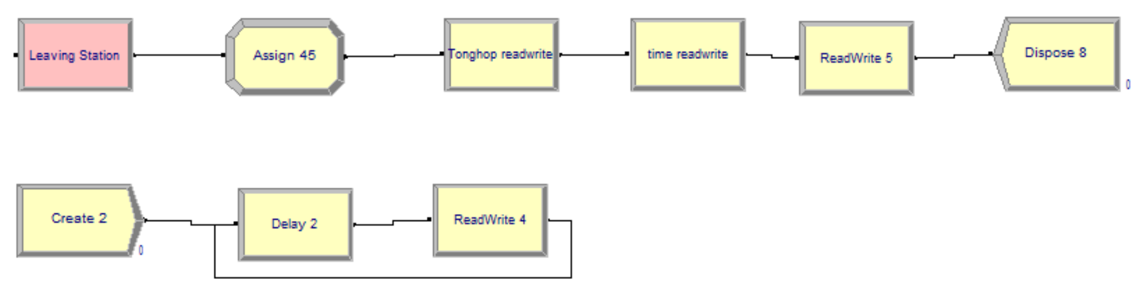
Test Area


Assign test
Biochemical test area
Diagnostic test area
Functional exploration area
Wait for result

Medical Area



Leaving model



APPENDIX B: Cplex source code

.mod file

```
*********************************************
 * OPL 12.6.2.0 Model
 * Author: Admin
 * Creation Date: Jun 30, 2021 at 10:46:53 AM
 *********************************************/

int NumTime=...;
int NumRoom=...;

range Room=1..NumRoom;
range Time=0..NumTime;

int MaxDoc=...;
float pat[Room][Time]=...;

dvar boolean x[Room][Time];
dvar int+ P[Room][Time];
dvar int+ D[Room][Time];
dvar int+ doctor[Room][Time];
dvar int+ dif[Room][Time];

minimize
      sum(i in Room, j in Time) dif[i][j];

subject to{
forall (i in Room, j in Time:j==0){
P[i][j]==0;
D[i][j]==0;
doctor[i][j]==0;
forall (i in Room, j in Time: j >1){
doctor[i][j]>=1;
}
constraint_1:
forall (i in Room, j in Time){
dif[i][j] == D[i][j]-P[i][j];
}
constraint_2:
forall(i in Room, j in Time:j>0){
D[i][j] == pat[i][j] + dif[i][j-1];
}
constraint_3:
forall (i in Room, j in Time:j>0){
P[i][j]*(1/15)<=doctor[i][j];
}
constraint_4:
forall (i in Room){
```

```
sum(j in Time)P[i][j]*(1/15)>=0.6*sum(j in Time)doctor[i][j];
}
constraint_5:
forall (j in Time){
sum(i in Room)doctor[i][j]<=MaxDoc;
}
constraint_6:
forall (i in Room,j in Time){
D[i][j]<=x[i][j]*1000000;
}
constraint_7:
forall (i in Room, j in Time){
doctor[i][j]>=x[i][j];
}
constraint_8:
forall (i in Room, j in Time:j>1){
doctor[i][j]<=doctor[i][j-1];
}
constraint_9:
forall(i in Room){
sum(j in Time)P[i][j]==sum(j in Time)pat[i][j];
}
}
}
```

.dat file

```
/*********************************************
 * OPL 12.6.2.0 Data
 * Author: Admin
 * Creation Date: Jun 30, 2021 at 10:46:53 AM
 *********************************************/
MaxDoc = 16;
NumTime = 10;
NumRoom = 8;
SheetConnection Data("a.xlsx");
pat from SheetRead(Data,"Sheet1!A1:H11");
```

APPENDIX C: Number of patients in each clinic room

No.	Clinic Room	Number of patients	Percentage
1	Nội Tổng Quát	576	21.44
2	Tim Mạch Can Thiệp	286	10.64
3	Nội Tim Mạch	201	7.48
4	Nội Thận	184	6.85
5	Nội Tiết	176	6.55
6	Cơ Xương Khớp	153	5.69
7	Phẫu Thuật Tim	142	5.28
8	Nội Tiêu Hóa	132	4.91
9	Ghép Thận	101	3.76
10	Nội Thần Kinh	98	3.65
11	Tai Mũi Họng	94	3.50
12	Ngoại Thần Kinh	86	3.20
13	Chỉnh Hình	76	2.83
14	Viêm Gan	68	2.53
15	Ngoại Tiết Niệu	57	2.12
16	Ngoại Tiêu Hóa	54	2.01
17	Nội Phổi	52	1.94
18	Ngoại Gan Mật	37	1.38
19	Mắt	23	0.86
20	Phẫu Thuật Mạch Máu	22	0.82
21	Gamma Knife	21	0.78
22	Thẩm Phân Phúc Mạc	19	0.71
23	Ngoại Lồng Ngực	13	0.48
24	Phẫu Thuật Tim Trẻ Em	6	0.22
25	Thận Nhân Tạo	4	0.15
26	Nhiệt Đới	2	0.07
27	Cận Lâm Sàng	2	0.07
28	Phỏng	1	0.04
29	Răng	1	0.04
Total		2687	100

APPENDIX D: The survey of tests

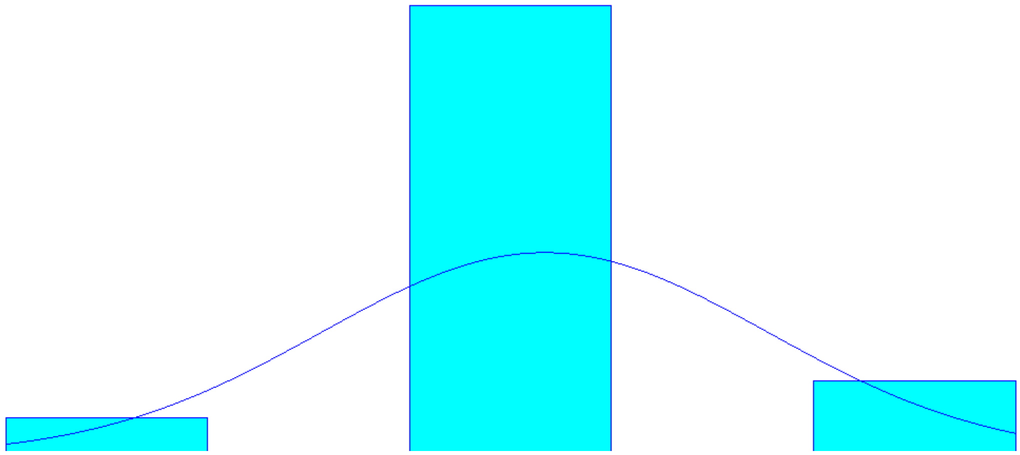
No.	Blood	Urine	Xray	CT	MRI	ECG	Ultrasound	Endoscopic
1	0	0	1	0	1	0	0	1
2	1	1	1	0	0	1	0	1
3	1	0	1	0	1	1	0	0
4	1	1	1	0	0	1	0	0
5	1	1	1	0	0	1	0	0
6	1	1	1	0	0	0	0	0
7	1	0	0	0	0	1	0	1
8	1	0	1	0	0	0	0	0
9	1	1	1	1	0	1	0	0
10	1	0	1	0	0	1	0	0
11	1	0	1	0	0	1	0	1
12	1	1	1	0	1	1	0	0
13	1	1	0	0	0	1	0	1
14	1	0	1	0	0	1	0	0
15	0	0	1	1	1	1	0	0
16	1	0	1	0	0	1	0	0
17	1	1	1	0	0	0	1	0
18	1	1	1	0	1	1	0	0
19	1	1	1	0	0	0	1	0
20	1	0	1	1	0	0	1	0
21	1	0	1	0	1	1	1	1
22	1	1	0	0	0	1	0	0
23	1	1	1	0	0	1	0	1
24	0	1	0	1	0	1	0	0
25	1	1	0	0	0	1	0	0
26	1	0	1	0	0	1	0	0
27	0	0	1	0	0	1	0	1
28	1	1	1	0	0	0	0	1
29	0	1	1	0	1	1	0	1
30	1	1	1	0	0	0	0	0
31	1	1	0	0	0	1	0	0
32	1	1	1	0	0	1	0	0
33	1	0	1	0	0	1	1	1
34	1	1	1	0	0	1	1	0
35	0	1	1	1	0	1	0	0
36	1	1	1	0	0	0	0	0
37	1	1	0	0	0	1	0	0
38	1	1	1	0	0	1	0	1

39	0	0	1	1	0	1	1	1
40	1	0	1	0	0	0	0	0
41	1	1	1	0	1	1	0	0
42	1	1	1	0	0	0	0	0
43	1	1	1	0	0	1	0	0
44	1	0	1	0	0	0	0	0
45	1	1	1	0	0	0	0	0
46	1	1	0	0	0	1	1	0
47	0	1	1	0	0	1	0	1
48	1	1	1	0	0	1	0	0
49	1	1	0	1	1	1	0	0
50	1	1	1	0	0	0	0	0
51	0	1	1	0	0	1	0	0
52	1	0	0	1	0	1	1	1
53	1	1	1	1	0	1	1	0
54	1	1	1	0	0	0	0	0
55	0	1	1	0	1	1	0	0
56	1	1	1	0	0	1	0	1
57	1	1	1	1	0	1	0	0
58	1	1	1	0	0	1	0	0
59	1	1	0	0	0	1	1	0
60	1	0	0	0	0	1	0	0
61	1	1	1	0	0	1	1	0
62	1	1	0	0	0	1	0	0
63	0	0	1	0	0	1	0	0
64	1	0	1	0	0	1	1	0
65	1	0	1	0	0	1	1	0
66	1	0	1	0	0	1	0	0
67	1	1	0	0	1	1	0	0
68	0	0	1	0	0	1	0	0
69	0	1	1	1	0	1	0	0
70	1	1	1	0	1	1	0	1
71	1	0	1	0	0	0	1	0
72	1	0	1	1	0	1	0	1
73	0	0	1	1	1	1	0	0
74	1	0	1	0	0	1	0	1
75	1	1	0	0	0	1	0	0
76	1	0	1	0	0	1	0	0
77	1	1	1	0	0	1	0	1
78	1	0	1	0	0	1	0	1
79	0	1	1	0	0	1	0	0

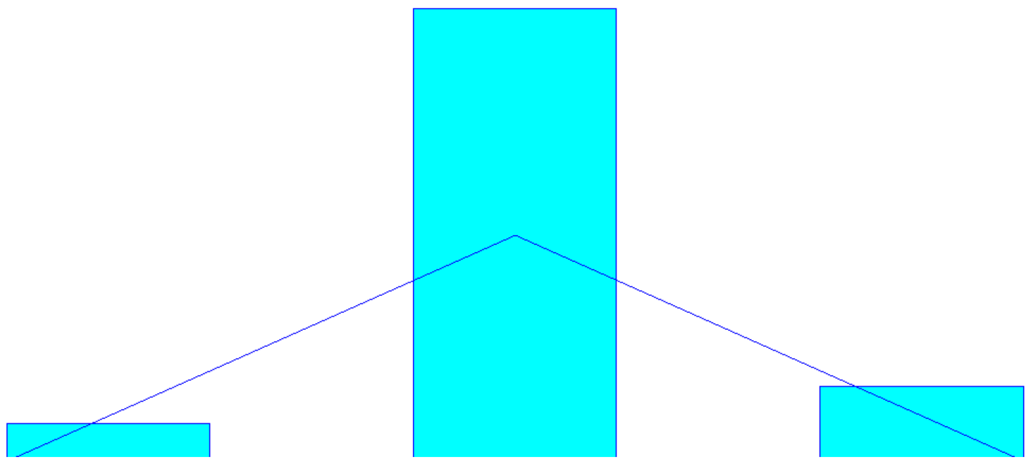
80	0	1	1	0	1	1	0	1
81	1	0	1	0	0	1	0	0
82	1	1	1	1	0	1	0	0
83	1	0	1	0	0	1	0	1
84	1	0	0	0	0	1	0	0
85	1	0	1	0	1	1	0	0
86	0	1	0	0	0	1	0	0
87	0	1	1	0	0	1	0	1
88	1	0	1	0	0	1	1	0
89	1	1	0	0	0	1	1	1
90	1	1	1	0	0	1	0	0
91	1	0	1	1	0	0	0	0
92	0	1	1	0	0	1	0	0
93	1	0	1	0	0	0	0	0
94	1	1	1	0	0	0	0	0
95	0	1	1	0	0	1	0	0
96	1	1	0	0	0	1	1	1
97	1	1	1	0	0	1	0	0
98	1	1	1	0	0	1	0	0
99	1	0	1	0	0	1	0	0
100	0	1	1	0	1	0	1	0

APPENDIX E: Input data analysis

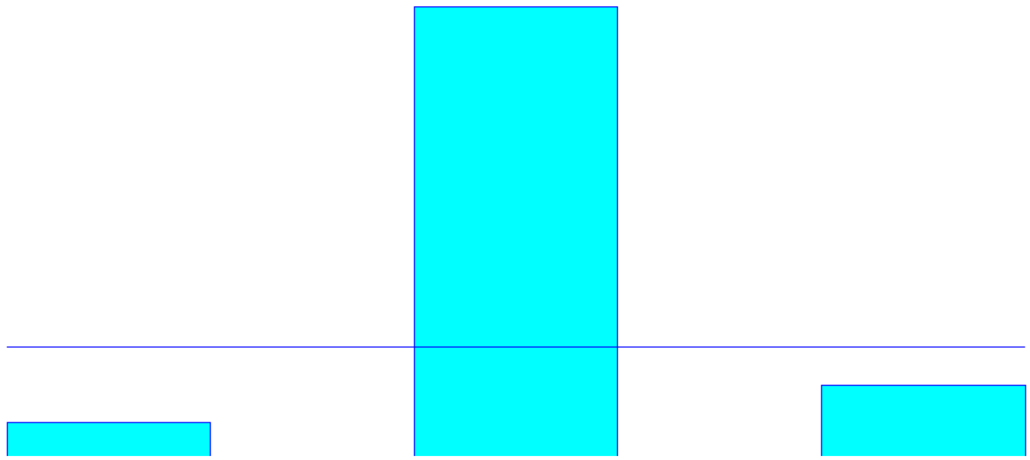
ClinicTime:



Distribution: Normal
Expression: NORM(244, 26.5)
Square Error: 0.322872

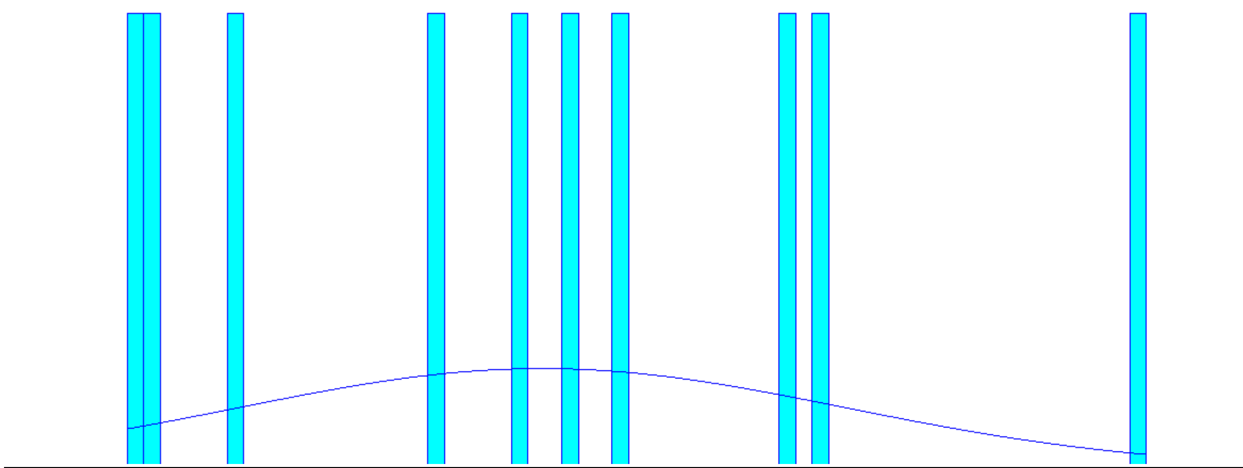


Distribution: Triangular
Expression: TRIA(180, 240, 300)
Square Error: 0.311822

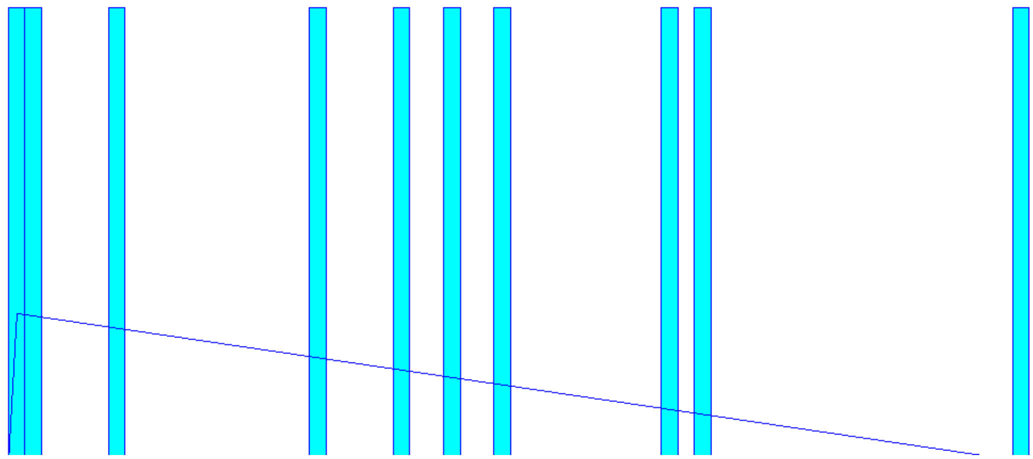


Distribution: Uniform
Expression: UNIF(180, 300)
Square Error: 0.462222

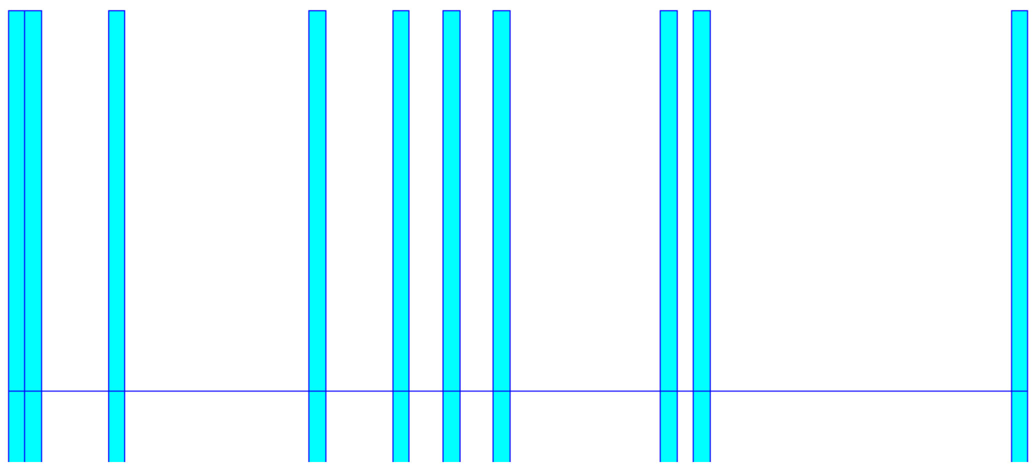
CTTime:



Distribution: Normal
Expression: NORM(384, 18.2)
Square Error: 0.084885

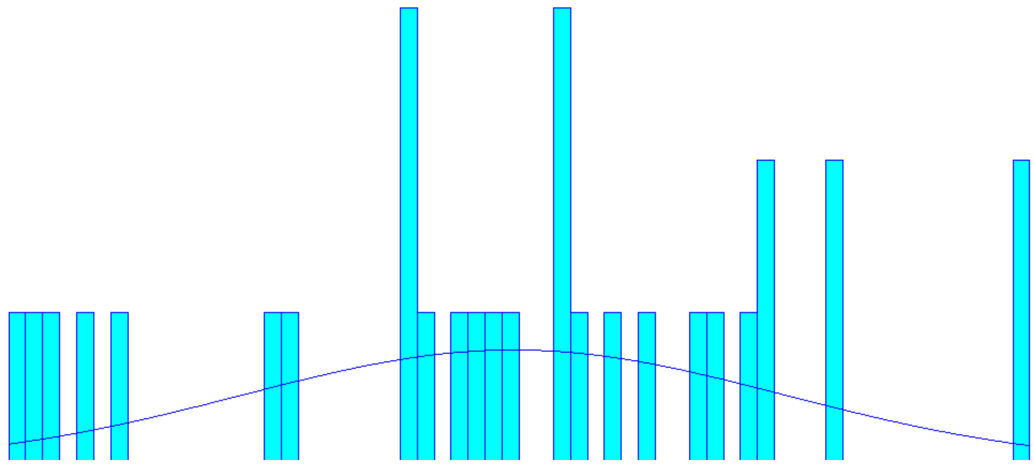


Distribution: Triangular
Expression: TRIA(360, 360, 421)
Square Error: 0.084163

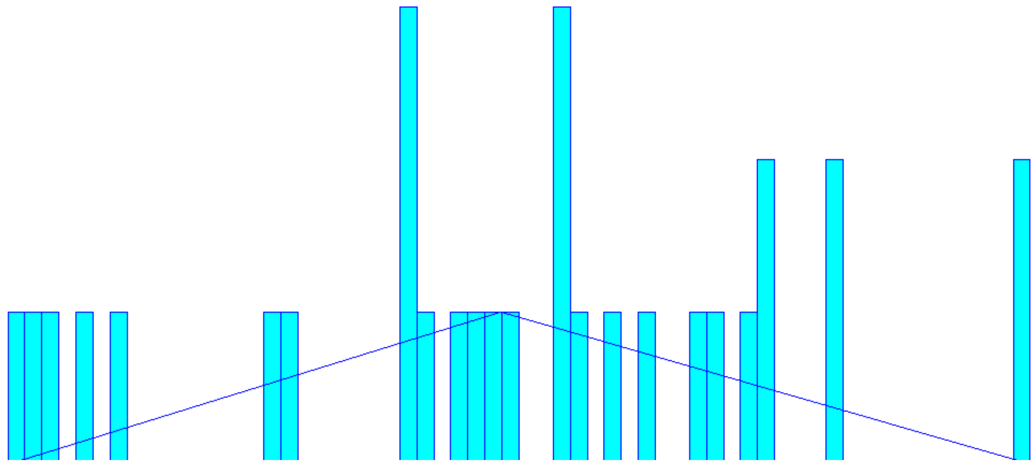


Distribution: Uniform
Expression: UNIF(360, 421)
Square Error: 0.083607

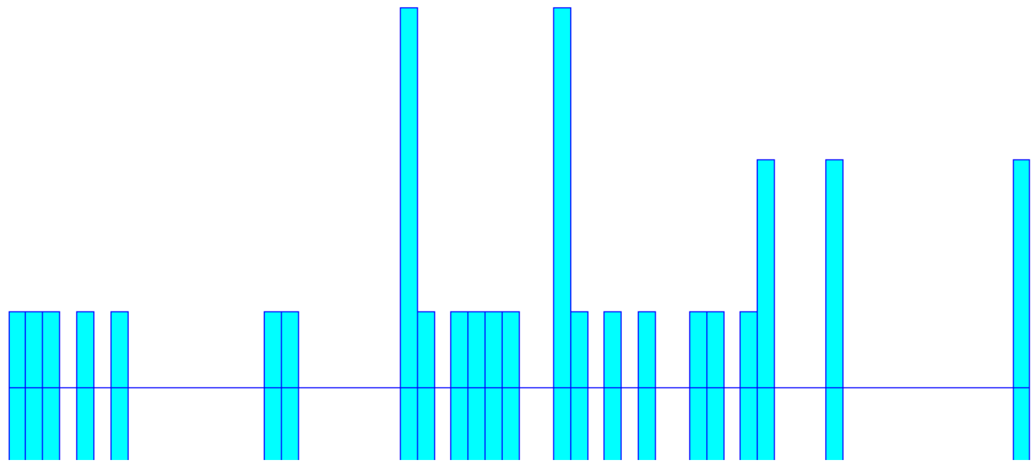
ECGTime:



Distribution: Normal
Expression: NORM(150, 15.9)
Square Error: 0.035899

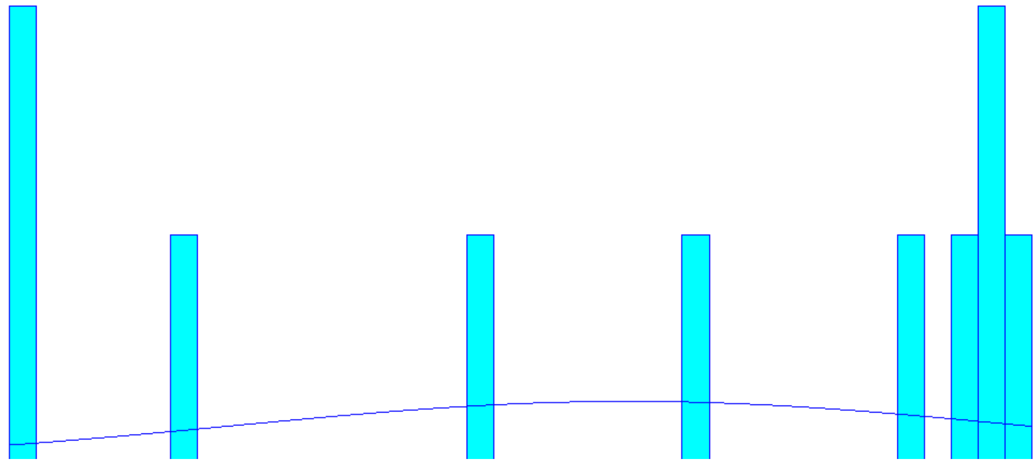


Distribution: Triangular
Expression: TRIA(121, 149, 181)
Square Error: 0.037099

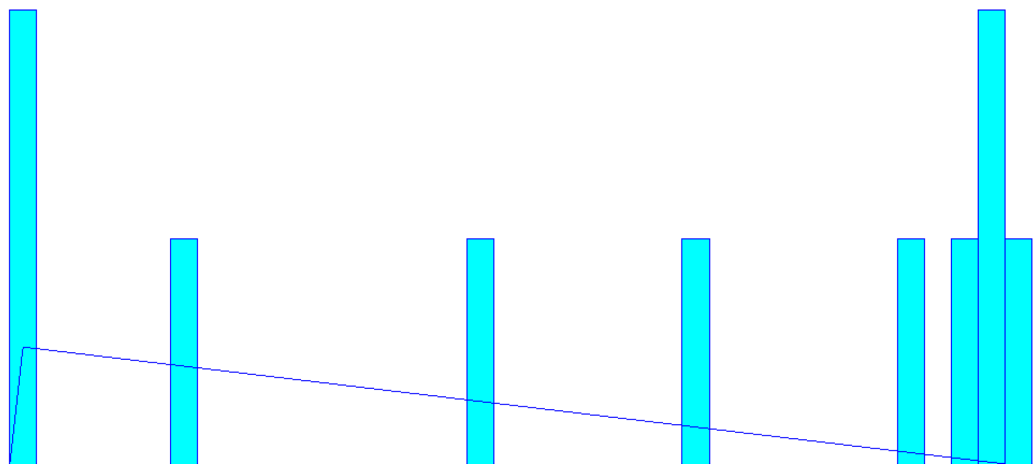


Distribution: Uniform
Expression: UNIF(121, 181)
Square Error: 0.036667

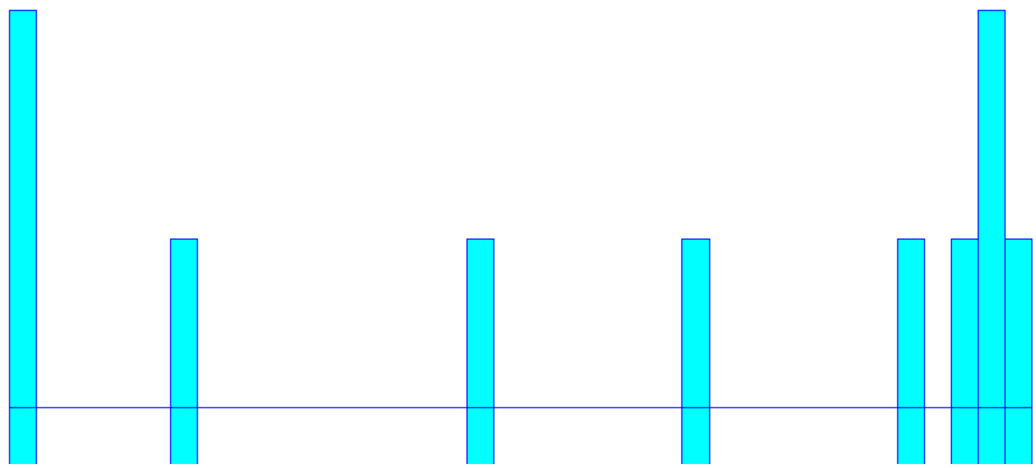
EndoscopicTime:



Distribution: Normal
Expression: NORM(326, 14.7)
Square Error: 0.122386

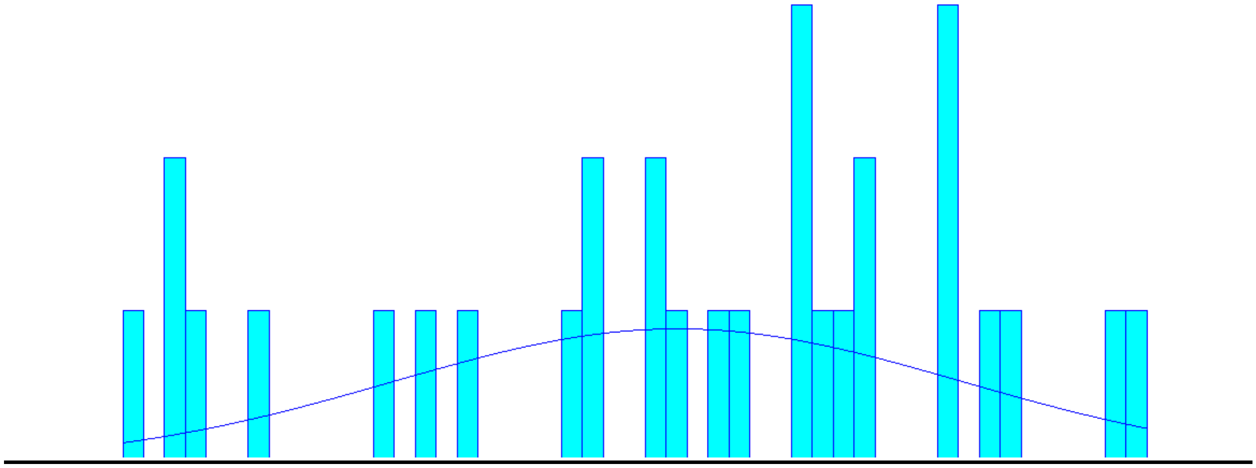


Distribution: Triangular
Expression: TRIA(303, 303, 341)
Square Error: 0.138026

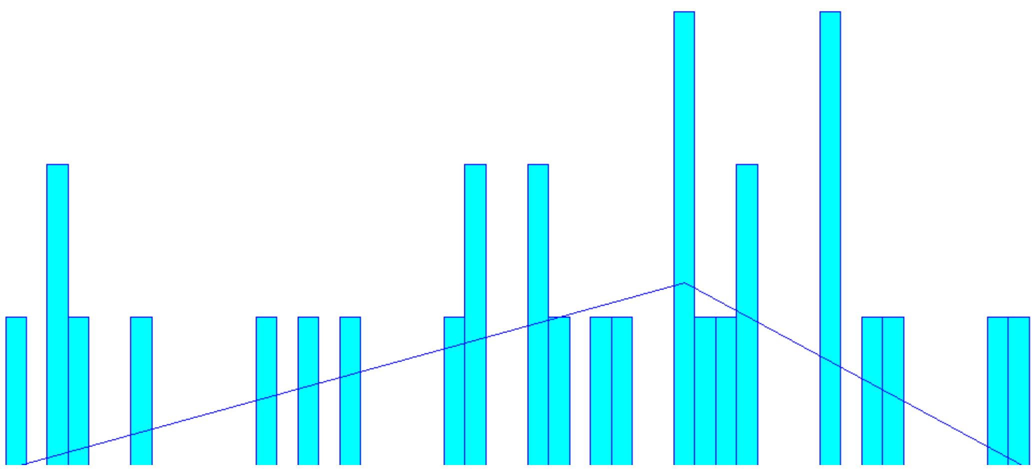


Distribution: Uniform
Expression: UNIF(303, 341)
Square Error: 0.113684

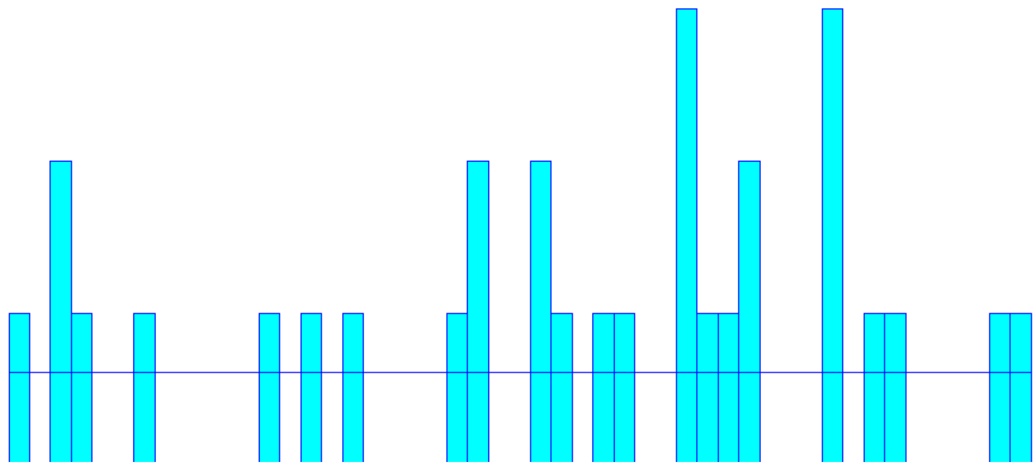
Insurancepaytime:



Distribution: Normal
Expression: NORM(89, 13.6)
Square Error: 0.035801

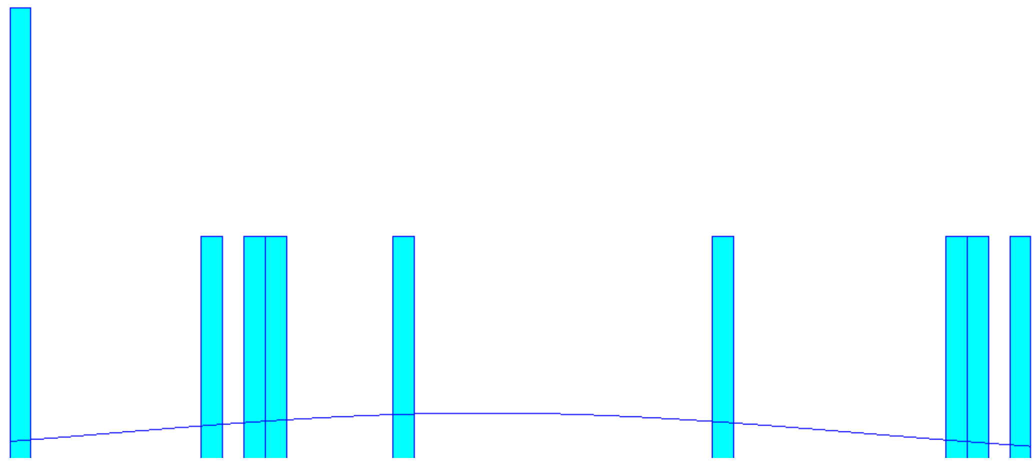


Distribution: Triangular
Expression: TRIA(62.5, 95, 112)
Square Error: 0.036093

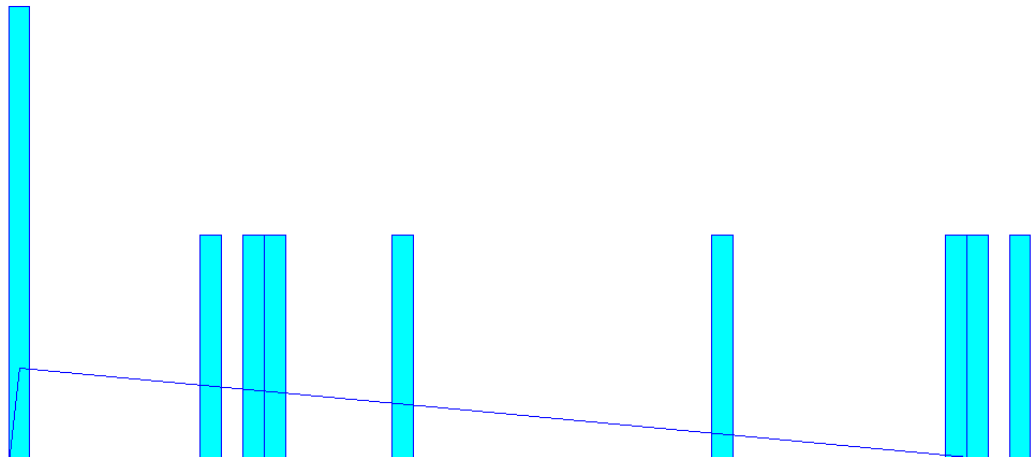


Distribution: Uniform
Expression: UNIF(62.5, 112)
Square Error: 0.035147

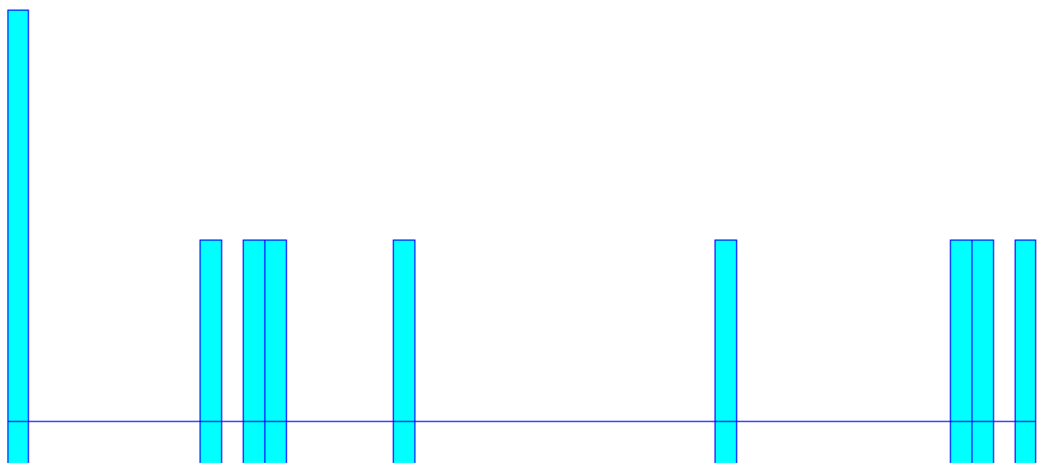
MRItime:



Distribution: Normal
Expression: NORM(571, 17.7)
Square Error: 0.106049

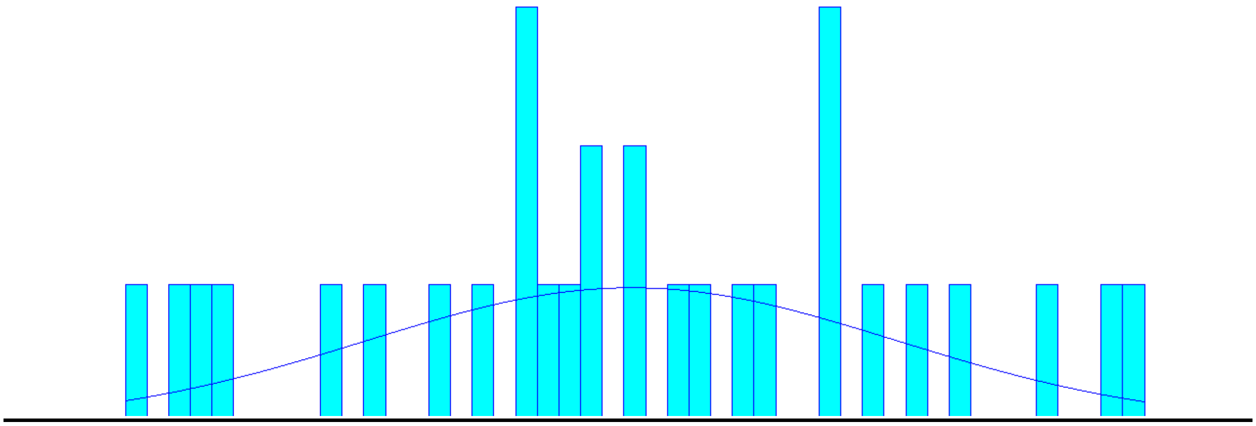


Distribution: Triangular
Expression: TRIA(549, 549, 597)
Square Error: 0.106894

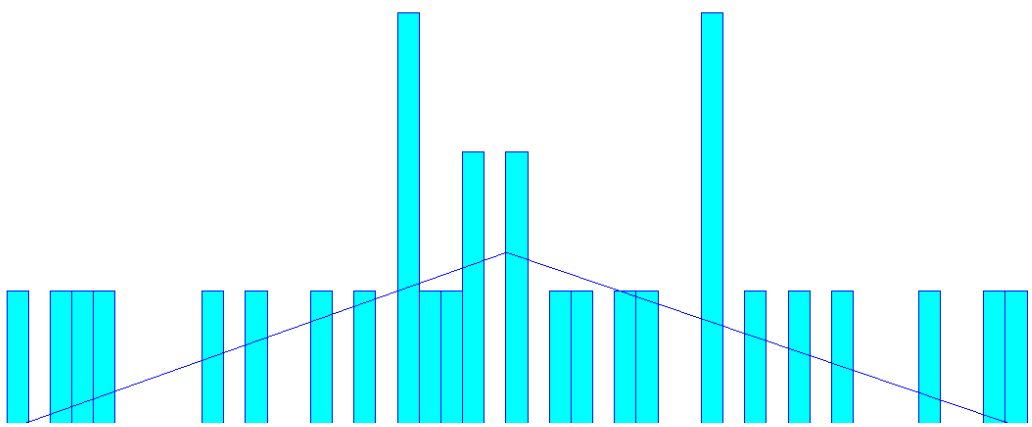


Distribution: Uniform
Expression: UNIF(549, 597)
Square Error: 0.099167

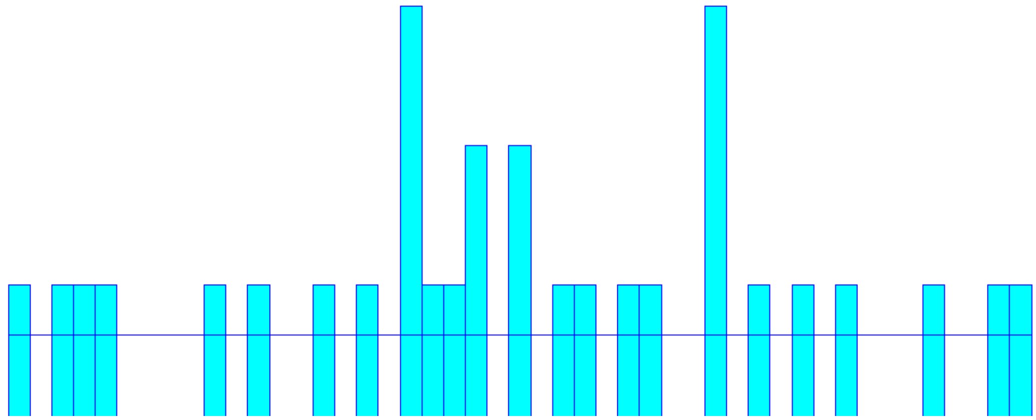
Noninsurancepaytime:



Distribution: Normal
Expression: NORM(93.8, 12.3)
Square Error: 0.028810

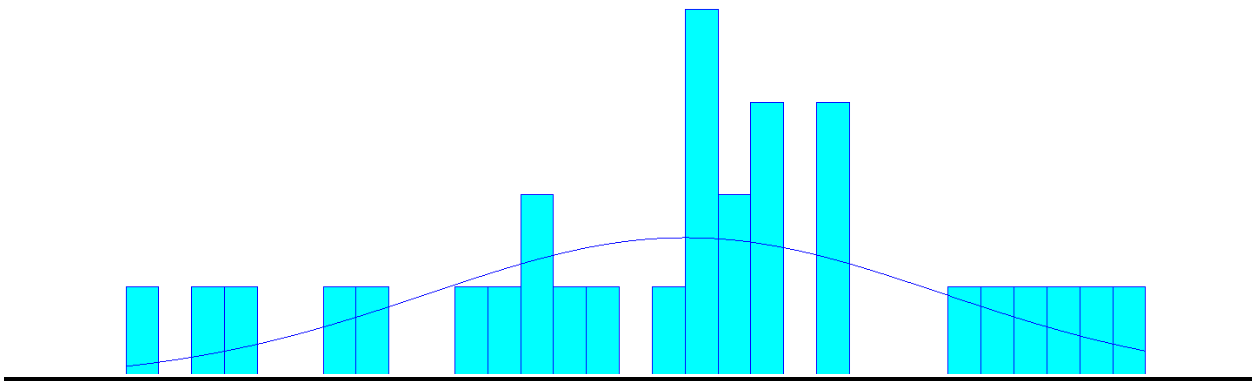


Distribution: Triangular
Expression: TRIA(70.5, 93.5, 118)
Square Error: 0.030205

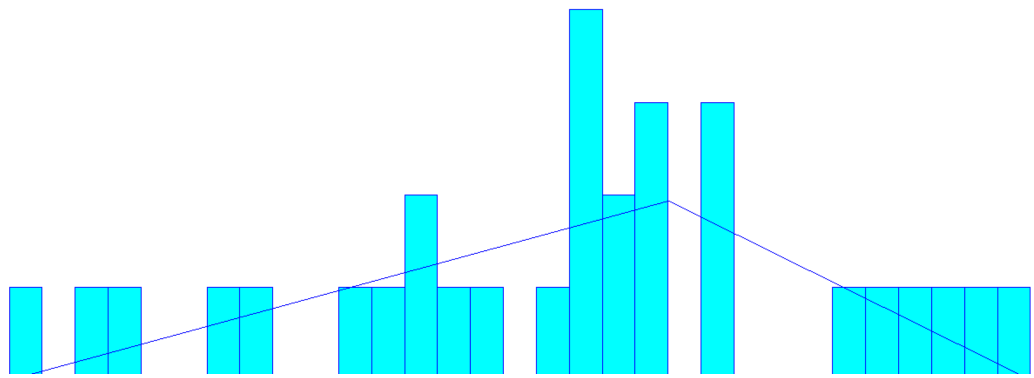


Distribution: Uniform
Expression: UNIF(70.5, 118)
Square Error: 0.029835

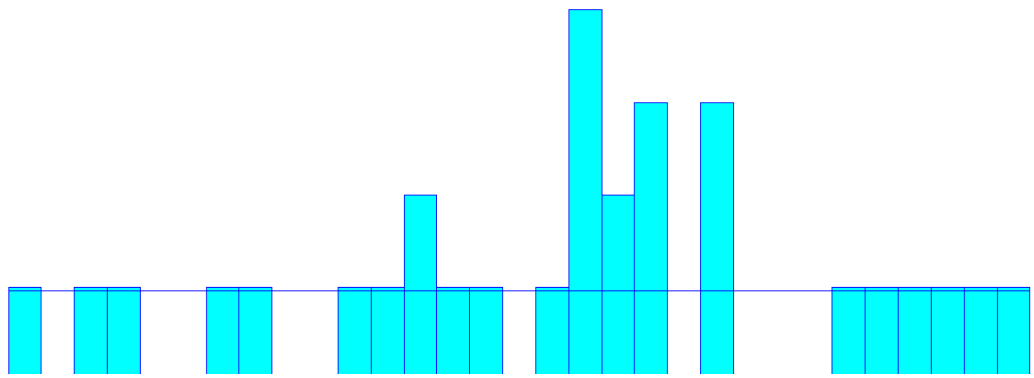
<u>Payfortestingtime</u>



Distribution: Normal
Expression: NORM(69.5, 7.8)
Square Error: 0.028646

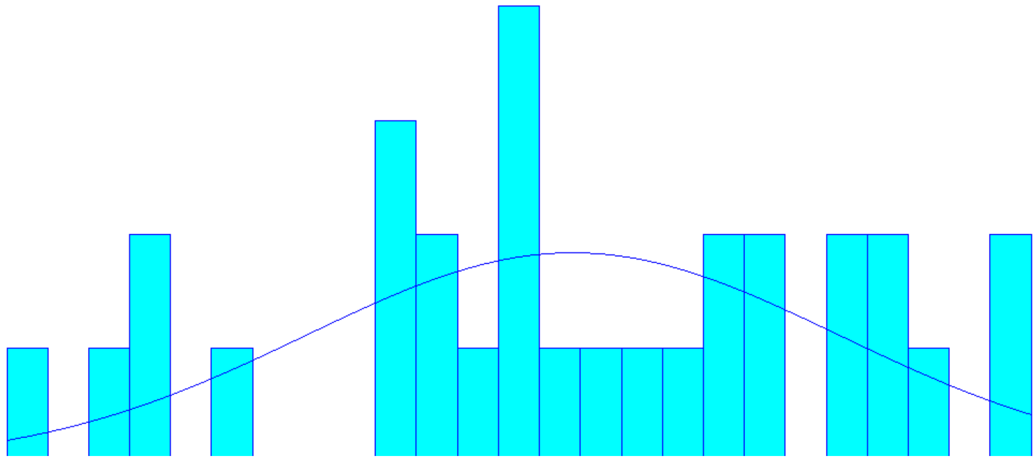


Distribution: Triangular
Expression: TRIA(52.5, 72.5, 83.5)
Square Error: 0.029547

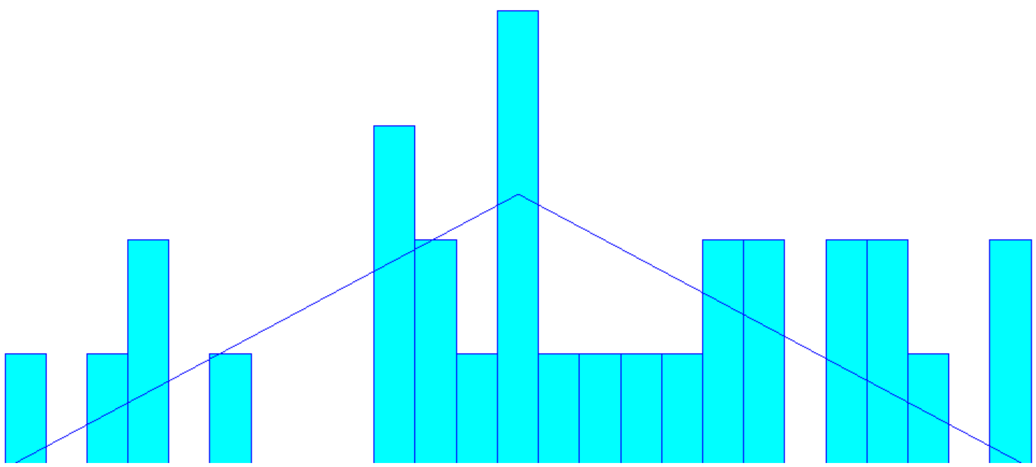


Distribution: Uniform
Expression: UNIF(52.5, 83.5)
Square Error: 0.032186

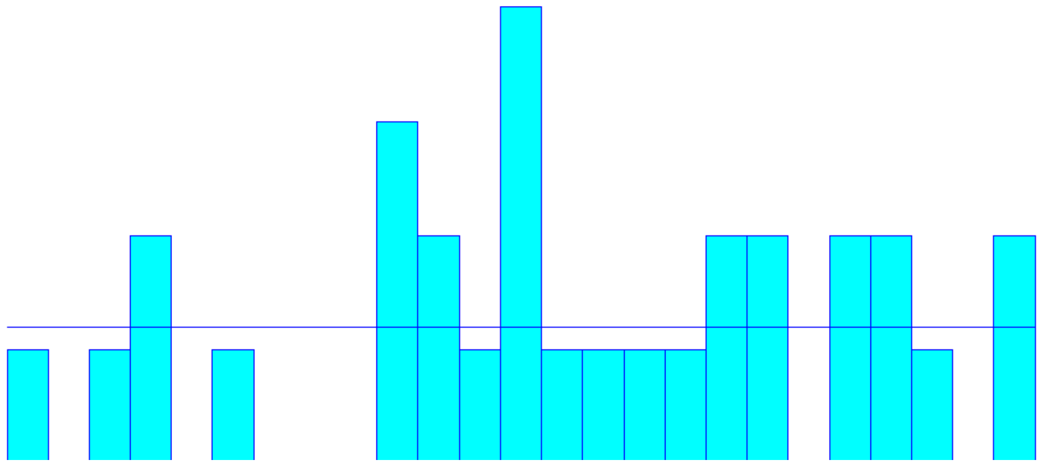
Receiveinsurancetime:



Distribution: Normal
Expression: NORM(45.3, 6.51)
Square Error: 0.027631

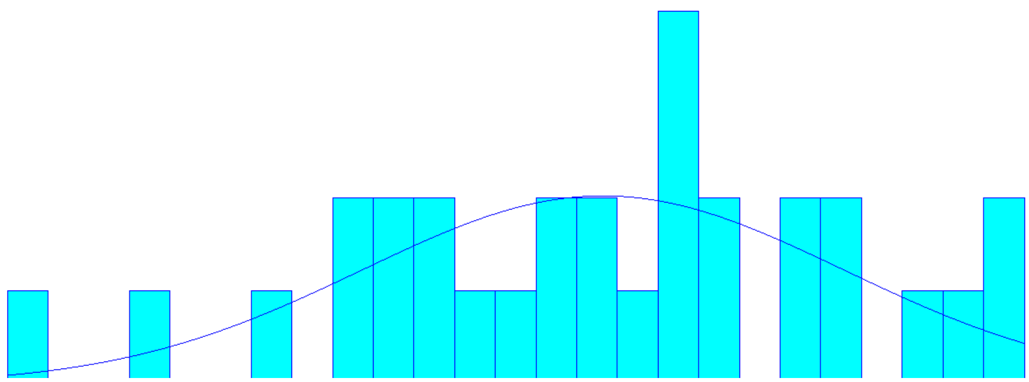


Distribution: Triangular
Expression: TRIA(31.5, 44, 56.5)
Square Error: 0.031259

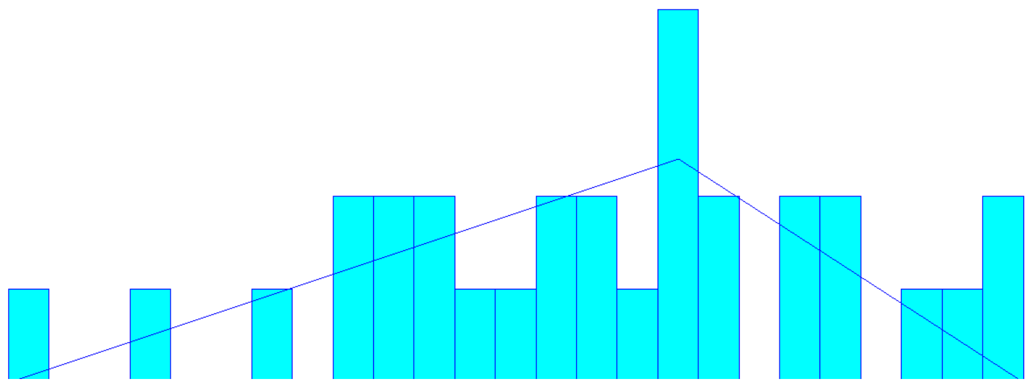


Distribution: Uniform
Expression: UNIF(31.5, 56.5)
Square Error: 0.028889

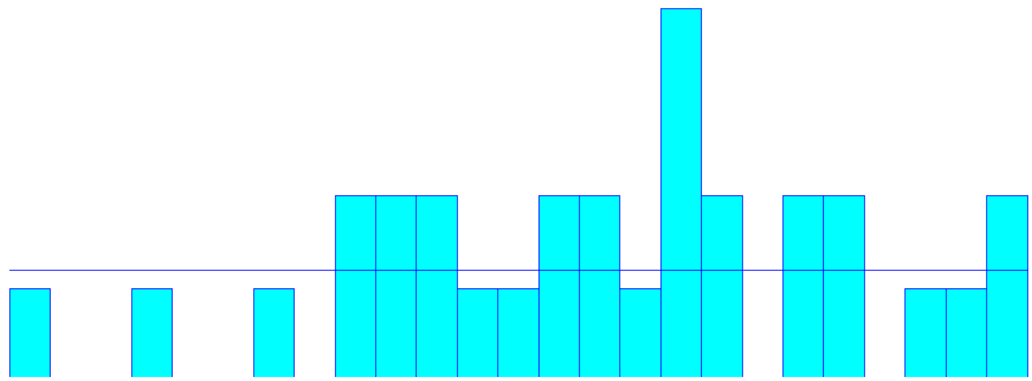
Receivenoninsurancetime:



Distribution: Normal
Expression: NORM(46.1, 5.92)
Square Error: 0.019826

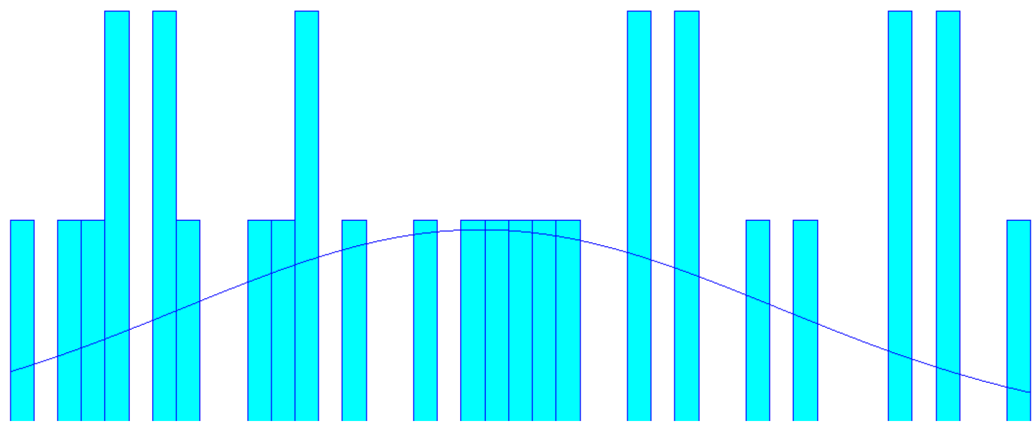


Distribution: Triangular
Expression: TRIA(31.5, 48, 56.5)
Square Error: 0.021265

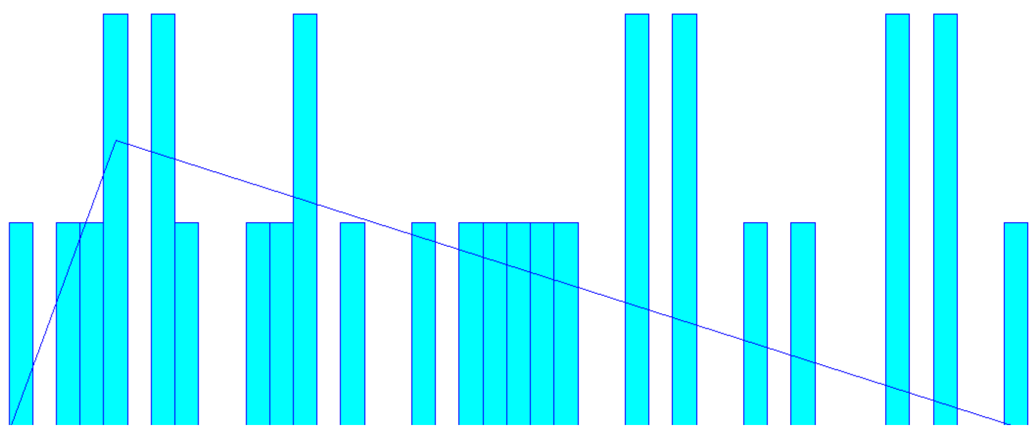


Distribution: Uniform
Expression: UNIF(31.5, 56.5)
Square Error: 0.026667

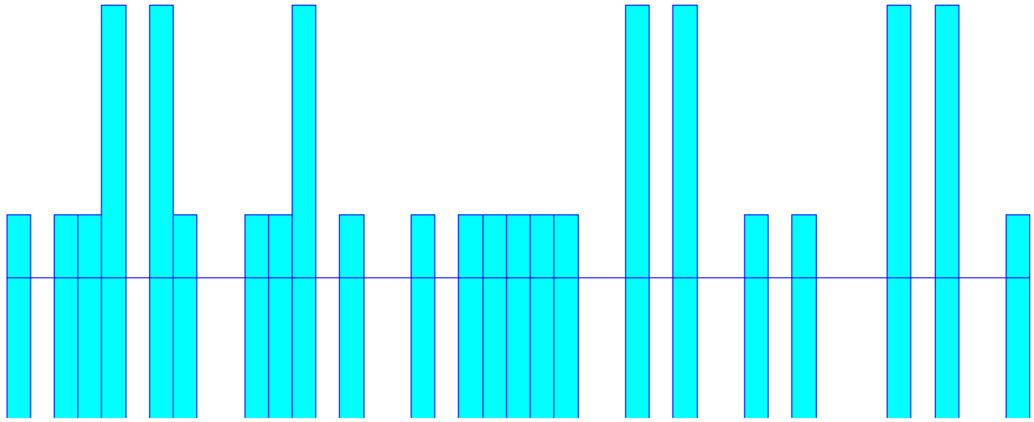
Takeurinetime:



Distribution: Normal
Expression: NORM(148, 12.5)
Square Error: 0.028748

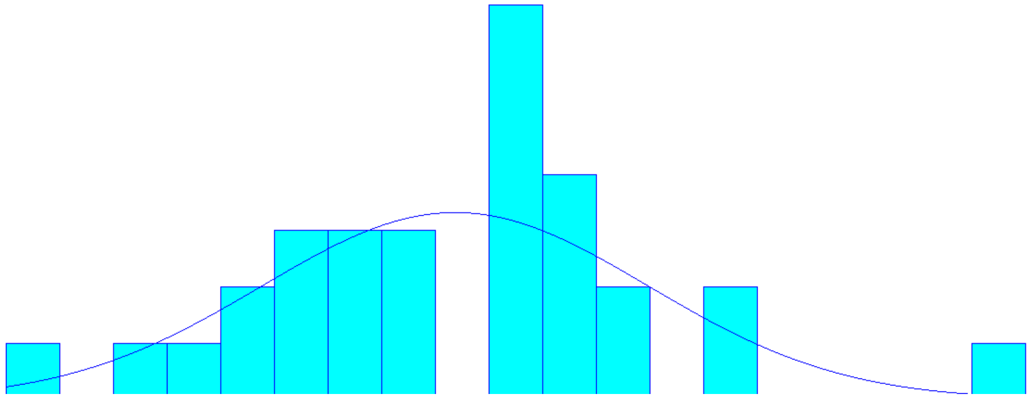


Distribution: Triangular
Expression: TRIA(129, 133, 172)
Square Error: 0.029378

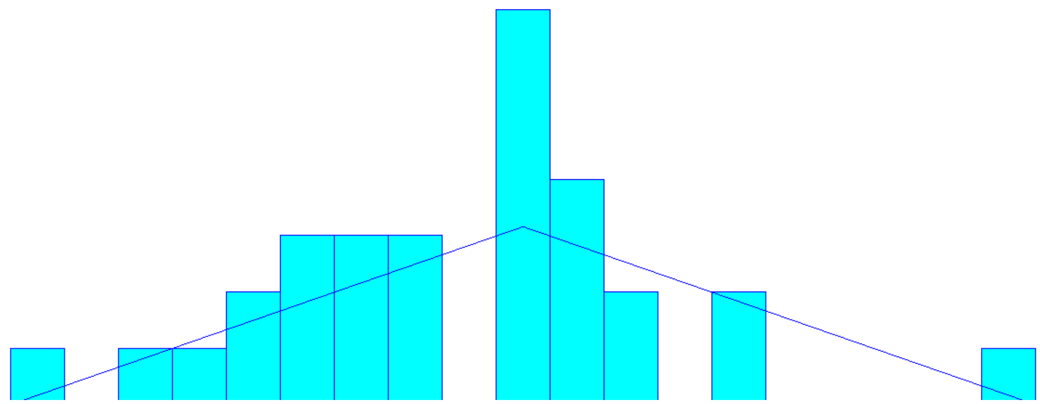


Distribution: Uniform
Expression: UNIF(129, 172)
Square Error: 0.025633

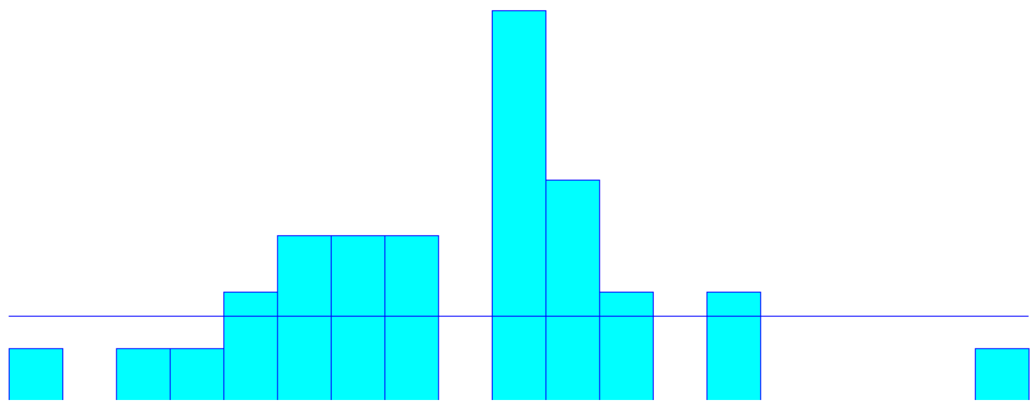
<u>Countertime:</u>



Distribution: Normal
Expression: NORM(28.9, 3.6)
Square Error: 0.037800

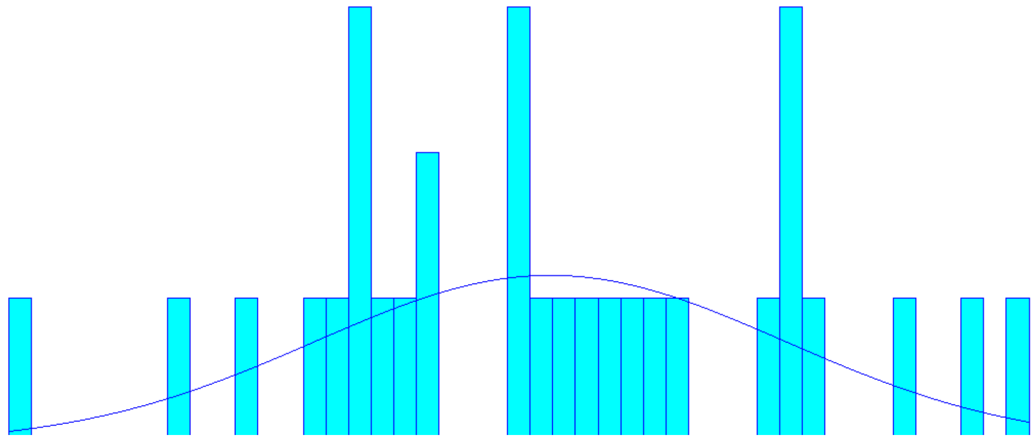


Distribution: Triangular
Expression: TRIA(20.5, 30, 39.5)
Square Error: 0.042805

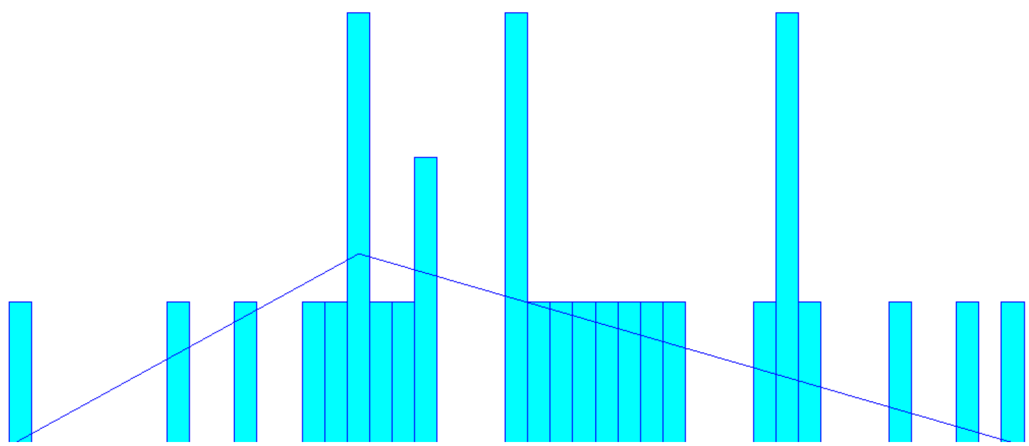


Distribution: Uniform
Expression: UNIF(20.5, 39.5)
Square Error: 0.067368

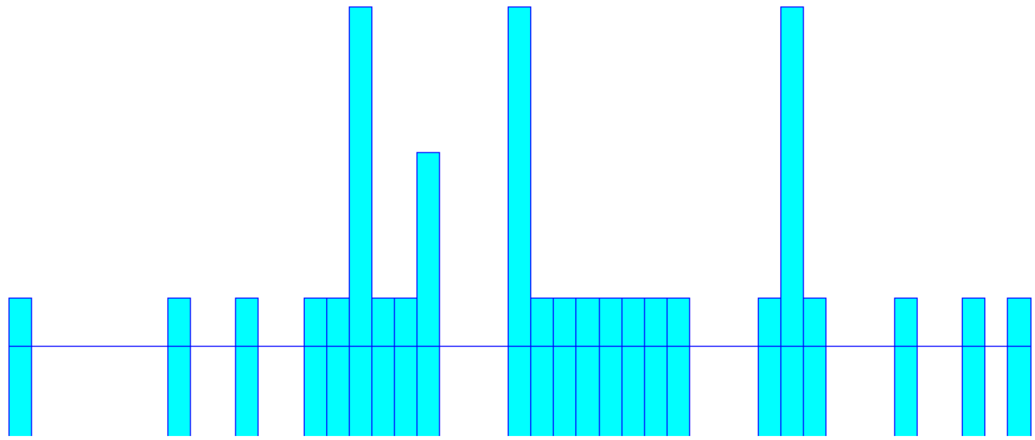
Timeregistration:



Distribution: Normal
Expression: NORM(45.4, 10.4)
Square Error: 0.029231

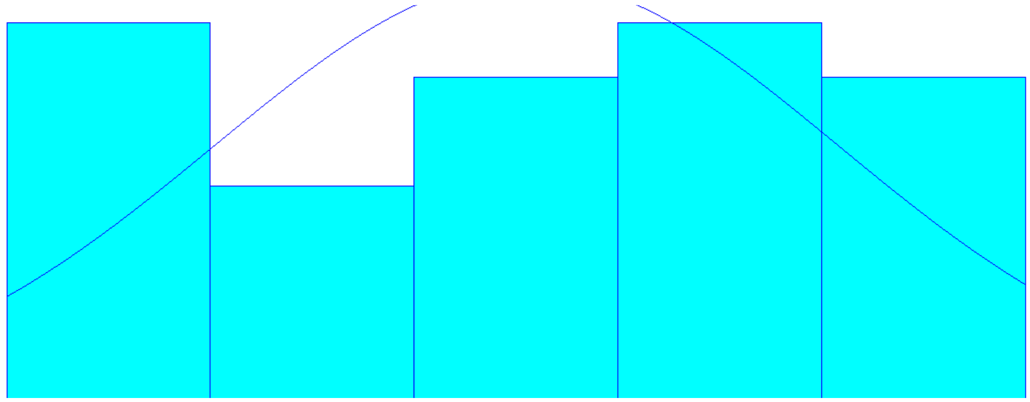


Distribution: Triangular
Expression: TRIA(21.5, 37, 66.5)
Square Error: 0.030640

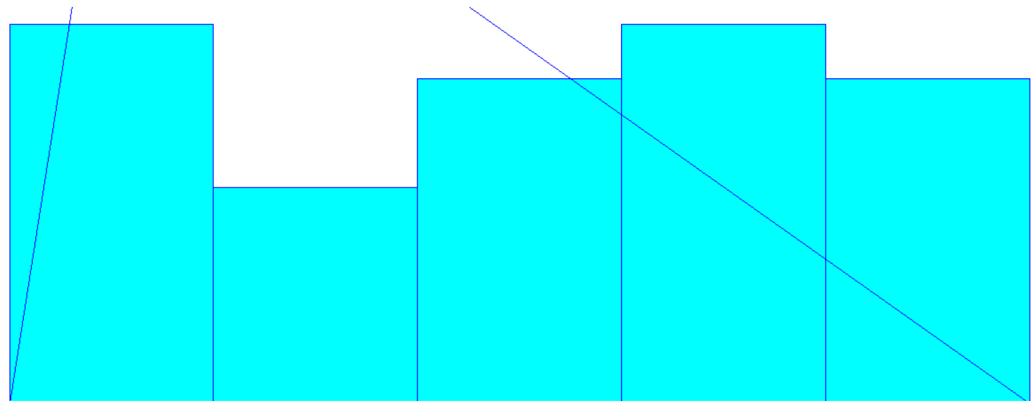


Distribution: Uniform
Expression: UNIF(21.5, 66.5)
Square Error: 0.033333

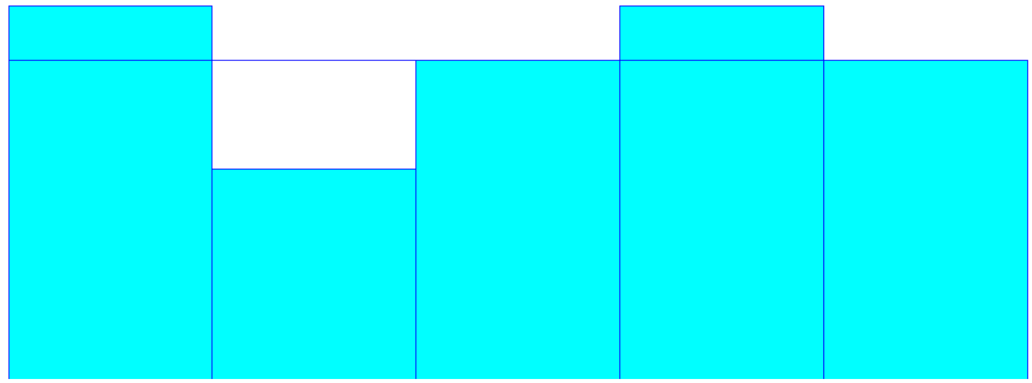
Ultrasoundtime:



Distribution: Normal
Expression: NORM(242, 36.2)
Square Error: 0.031169

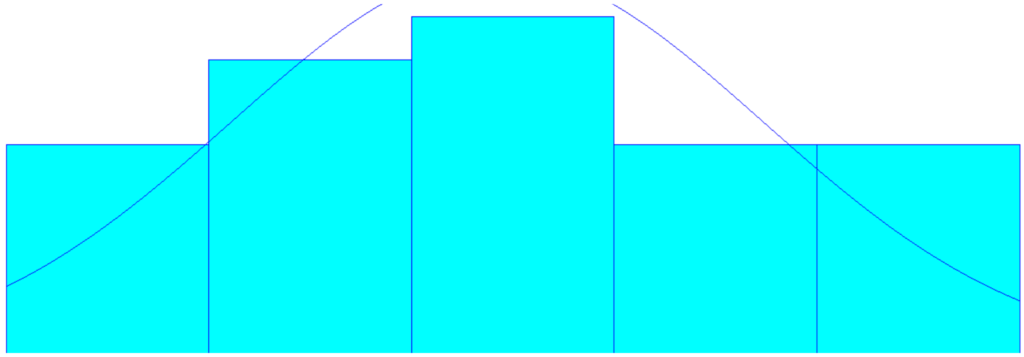


Distribution: Triangular
Expression: TRIA(182, 194, 300)
Square Error: 0.069383

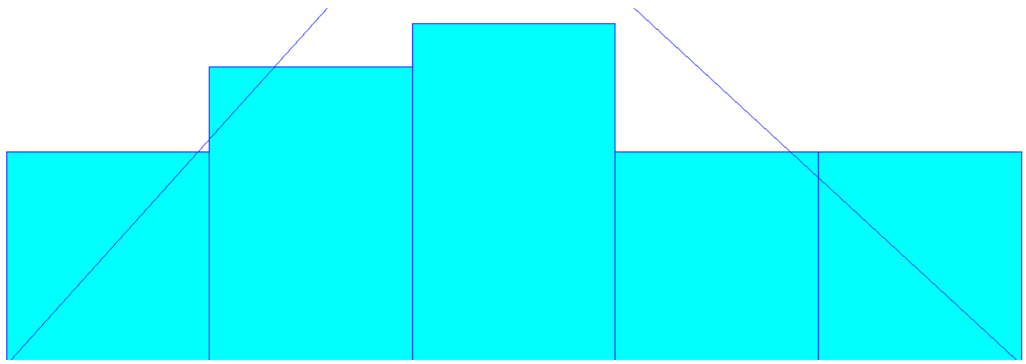


Distribution: Uniform
Expression: UNIF(182, 300)
Square Error: 0.006667

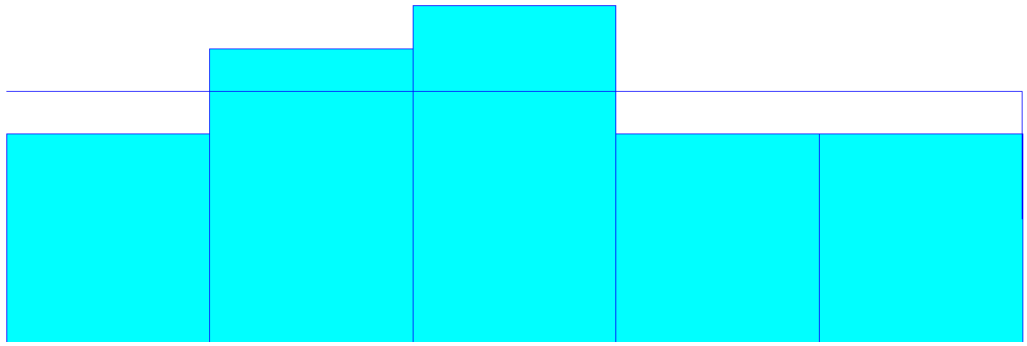
Xraytime:



Distribution: Normal
Expression: NORM(177, 28.3)
Square Error: 0.012772



Distribution: Triangular
Expression: TRIA(125, 174, 233)
Square Error: 0.026333



Distribution: Uniform
Expression: UNIF(125, 233)
Square Error: 0.008889