IMS, Simulation

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December 2, 2024

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1 Introduction

This project focuses on the process of creating a model for simulating the operations of a bank, based on observations of a Ukrainian bank in Kyiv. By using this model and conducting simulation experiments, it is possible to analyze the efficiency of various processes and their impact on the overall performance of banking operations under different conditions. The goal of the experiments is to evaluate how effectively the system is designed and to explore potential improvements by modifying certain influencing factors. Since making changes to real-world systems can be challenging and financially costly, it is advantageous to gain insights into the system's behavior using principles of modeling and simulation.

1.1 Authors and Sources

This project was developed by Nikita Koliada (xkolia00) and Pavlo Butenko (xbuten00). The info about the bank was gathered with the help of friends and family members who provided observations of the daily operations of a Ukrainian bank "Monobank" in Kyiv.

1.2 Model Validation

Since our model is based on real observations of the bank, we can validate its accuracy by comparing its predictions with the actual observed data. This direct comparison ensures that the outcomes generated by the model align with real-world behavior. Additionally, the simulation can reveal potential scenarios or hypothetical insights that were not immediately apparent during the initial observations. These insights can contribute to identifying opportunities for system improvements and optimization.

2 Analysis of the Topic and Methods/Technologies Used

2.1 Analysis of the bank structure and processes

By analyzing the information we got from people, we concluded the dynamics of customer interactions and time needed for various operations as well as likelihood of choices and personal in various sections. We concluded the bank service usages such as reception, ATMs, possibility of taking coffee and various banking activities such as bank registration, various consultation on loans, frauds and investment opportunities observed during the study. By analyzing these observations, we can simulate the bank's operations and identify issues affecting service efficiency and customer satisfaction.

2.2 Methods Used

We created the simulation using the C++ programming language with the help of the SimLib library. C++ supports Object-Oriented Programming, which made it easier to define interactions between different parts of the system. The SimLib library provides modules to represent and simulate our model. Main focus was on the system's logic and run experiments.

2.3 Technologies Used

For building the simulation, we used the SimLib library and the C++ language. We used the official version of the SimLib library [2] and the unistd.h for getopt operation. Additionally, standard C++ libraries were also used.

3 Concepts

In this section, we will describe the design of the conceptual model based on a queuing system (SHO) [1]. The model is designed to represent key parts of the system and their behaviors. We model visitors and cash guys as individual processes, visitors behave based on probabilities of what they will choose, they interact with queues such as coffee machines, consultants, complaint desk, voucher machines and reception.

3.1 Representation of the model

Our model is represented as a Petri Net [1]

3.2 Description of the conceptual model

Visitors come to the bank during work hours 9-18, exponentially every 5 minutes, and have 4 ways to go, first is to go to the reception, which is 20% chance. With the 40% chance the visitor can go to the ATMs section, another 30% chance that he will go for a consultation and 10% to make a complaint.

Reception

At the reception there is only one person and the visitor talks to the receptionist in a normal distributed with a mean of 5 minutes and a standard deviation of 2 minutes and then with 20% chance either leaves or goes back to the start where he can choose again where to go. Also if receptionist is busy for 4 minutes the visitor will go for a coffee.

ATMs

There are 3 ATMs and the visitor takes exponentially 3 minutes to finish his operations with it. Then the visitor leaves the bank. Every exponentially 6 hours the guy comes and refills all ATMs which takes 30 min. Every visitor will leave if ATMs are busy during that time.

Consultations

If the visitor comes to the Consultation section, first he needs to take the voucher in a voucher machine which takes norm(30, 10) [1] seconds. But the visitor can skip voucher machine if he is a premium user which a 15% chance and goes straight to a one of 4 available consultants who prioritize premium users as well. If all consultants are busy, visitors as well as premium ones will **go for a coffee** and then back to the consultants queue. When the consultant is finally available, he checks the visitor's documents, which takes a minute and in 75% cases they are valid. If they are not valid the visitor will make a complaint at the **complaint desk** in 75% cases or he leaves. When the documents are valid there are several possibilities for a consultation:

- with the 50% chance he will do a registration process which takes norm(20, 5) minutes and then leaves.
- with the 20% chance he chooses an investment plan consultation which will take norm(40, 10) minutes and then leaves.
- 10% chance he will choose a fraud investigation which will take norm(10,2) in 20% cases it would be solved and the visitor will leave, otherwise he either leaves (in 20% cases) or goes to make a complaint at the **complaint desk**.
- in final 20% cases the visitor will go for a loan process which requires a background check with 80% success rate then waits to finish the process norm(30, 5) minutes and leaves, otherwise the visitor in 40% cases will go to make a complaint at the **complaint desk**.

Complaint desk

At the complaint desk there is only one person to take these complaints and he prioritizes the visitors that came to make a complaint from the consultations section. The complaint takes one minute to make and then the visitor leaves.

Coffee machine

For visitors who chose to go for a coffee, there are 3 available coffee machines. The process of making a coffee takes a minute then the visitors come back to the queue they came from.

[1] norm(x, y) - normal distribution time where x is the mean, and y the standard deviation

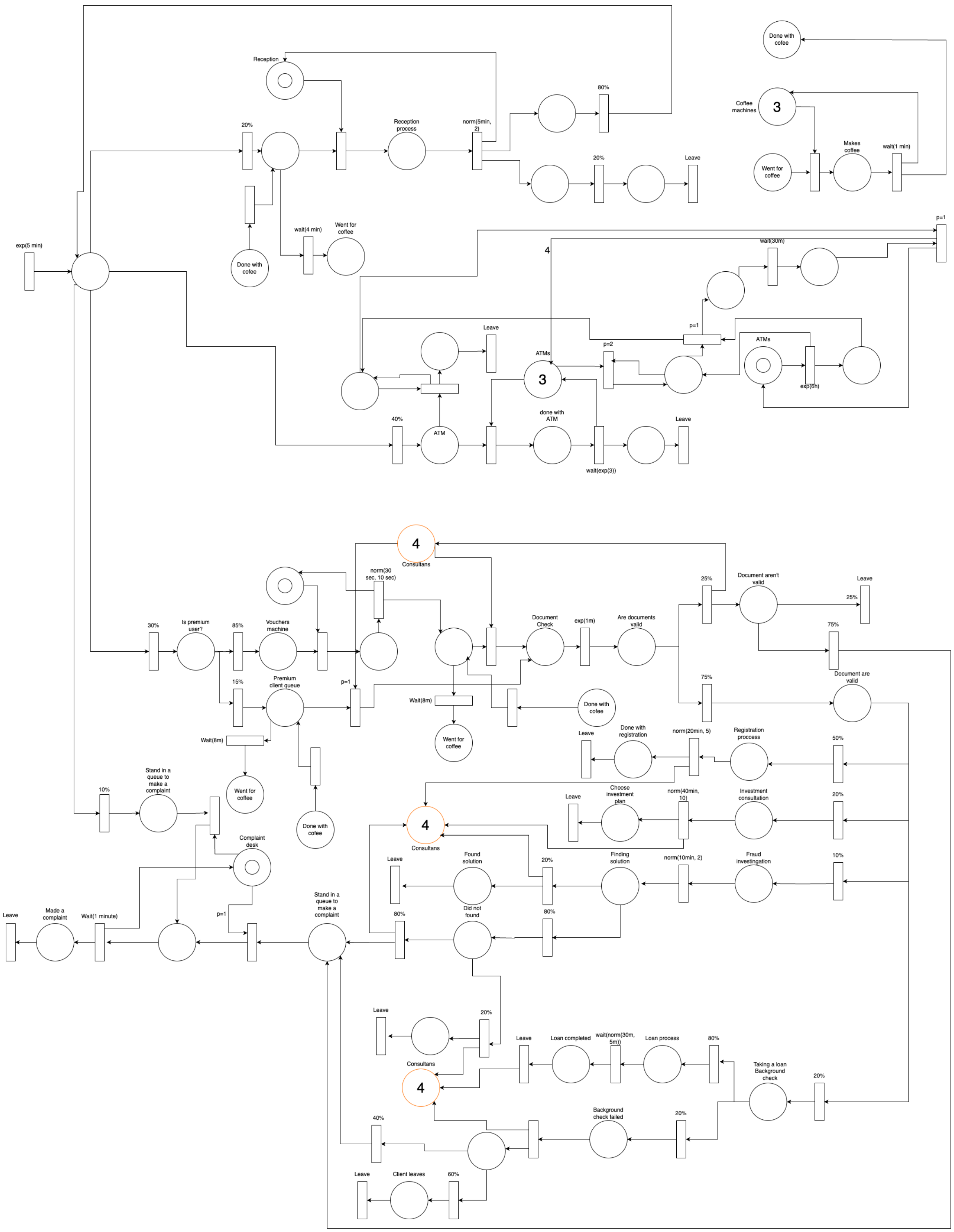

Figure 1: Petri net of the bank

4 Implementation

The implementation was written in C++ as mentioned in in section 2.3 , and is based on the Petri net we described earlier [1]

4.1 Structure

main.cpp file contains the whole implementation of our model, which includes the usage of simlib [2] functionality such as Facility to simulate Voucher Machines, Reception and Complaint Desk (exclusive access and service priority), Store to simulate Consultants and Coffee machines (store capacity can be changed dynamically), Queue to simulate different queues for specific action, Process to simulate visitors and their needs as well as ATMs replenishment and Event to generate new visitors.

4.2 Usage

In order to run the simulation, you need to run 'make' command. Then run this command:

```
./bank -a -c -s
```

- `s`: The number of consultants.
- `c`: The number of coffee machines.
- `a`: The number of ATMs.

Default Values

If no arguments are provided, the program uses the following default values:

- `s` (consultants): `5`
- `c` (coffee machines): `3`
- `a` (ATMs): `4`

The script will generate a new file 'bank.out' where the statistics about the simulation will be displayed. The statistics contain information such as average, minimum, maximum waiting time in queues, total visitors, rates like consultation success rate, what different consultation processes were taken and average utilization in every store.

5 Simulation experiments

During the simulation processes we experimented with number of consultants, coffee machines, ATMs in order to see the interesting states of the model and to find the optimal parameters for the model. In total we made 4 experiments where the optimal numbers were found. During each experiment, we run the program 6 times to find the average. As a conclusion we figured out a final combination of these parameters and the optimal simulation model.

5.1 Experiments

First we simulated with the observed value for number of consultants, ATMs and coffee machines, here is the table of simulation:

Description	**Value**
Total visitors per day	110.4
Reception utilization	0.2420253
Reception avg time in queue	130.96596 seconds
Voucher usage	36.2 requests
Voucher avg utilization	0.03272364
Consultant utilization	1.6859183
Consultant avg time in queue	244.0421 seconds
Coffee machine usage	4.6 operations
Coffee machine avg capacity	0.00851892
ATM machine usage	47.2 enter operations
ATM avg time in queue	236.7798 seconds
Visitors left due to ATM replenishment	4.8 visitors
Complaint desk usage	20.4 requests
Percentage of invalid documents	18.846%
Percentage of successful consultations	72.832%
Loan services count	6.4
Investment services count	7.8
Successfully processed fraud count	0.8
Registration count	16.6

Table 1: The first experiment with the observed data.

5.1.1 Experiment 2

In this experiment we change number coffee machines in order to find optimal number of coffee machines to have an optimal average time of waiting for visitors:

Description	1 Coffee Machine	2 Coffee Machines	4 Coffee Machines
Total visitors per day	106.36	84.5	94.2
Reception utilization	0.206143	0.2064824	0.229343
Reception avg time in queue	154.268 seconds	140.929 seconds	186.141 seconds
Voucher usage	34.6 requests	44.3 requests	39.2 requests
Voucher avg utilization	0.0171614	0.0256909	0.0248848
Consultant utilization	1.2987125	1.3127122	1.2922341
Consultant avg time in queue	196.222 seconds	200.225 seconds	265.557 seconds
Coffee machine usage	5.5 ops	3 ops	7.2 ops
Coffee machine avg capacity	0.00185185	0.00555556	0.0148148
ATM machine usage	58 ops	57 ops	54 ops
ATM avg time in queue	152.698 seconds	179.6094 seconds	168.766 seconds
Visitors left due to ATM replenishment	2.6 visitors	4.36 visitors	3.67 visitors
Complaint desk usage	20.5 requests	24.2 requests	28 requests
Percentage of invalid documents	23.33%	21.33%	18.89%
Percentage of successful consultations	75.56%	75.56%	69.43%
Loan services count	9.36	9	6.2
Investment services count	7.5	7.36	4.2
Successfully processed fraud count	0.2	0.5	1
Registration count	14.2	14.1	13

Table 2: Comparison of results for different coffee machines counts.

As we can see here, the number of coffee machines have no direct impact on its usage or availability as in almost all cases coffee machines are used rarely. The possible impact on number of coffee machines could have number of ATMs and Consultants as then there would be more queues hence bigger demand on coffee. But in current condition where there are 4 consultants and 3 ATMs, we concluded that only 1 coffee machine will have the same benefit as observed 3.

5.1.2 Experiment 3

In this experiment we change number consultants in order to optimal average number of visitors in queue for consultation.

Description	1 Consultant	2 Consultant	8 Consultant
Total visitors per day	112	116.5	112.5
Reception utilization	0.206844	0.24283125	0.25558975
Reception avg time in queue	99.8057 sec	189.22375 sec	168.9905 sec
Voucher usage	30.2 requests	38.75 requests	34 requests
Voucher avg utilization	0.0287875	0.03442625	0.0314587
Consultant utilization	0.92403025	1.2987125	1.49187
Consultant avg time in queue	465.016 sec	361.6175 sec	0 sec
Coffee machine usage	220.5 ops	28 ops	3 ops
Coffee machine avg capacity	0.408833	0.051351825	0.00555556
ATM machine usage	57.6 ops	54.25 ops	50.25 ops
ATM avg time in queue	184.719 sec	687.77475 sec	435.6455 sec
Visitors left due to ATM replenishment	3.25 visitors	4 visitors	8.25 visitors
Complaint desk usage	22.2 requests	26.25 requests	25.25 requests
Percentage of invalid documents	29.38%	27.893%	24.725%
Percentage of successful consultations	59.04%	57.7%	63.9875%
Loan services count	3.6	3.5	3.5
Investment services count	4.6	5.25	5.75
Successfully processed fraud count	0.4	1.5	0.5
Registration count	9.4	15.25	18.5

Table 3: Comparison of results for different Consultant counts.

During this experiment, we changed number of consultants and found out that the observed data as we mentioned it data in the beginning [1] is the optimal one because if have only one or 2 consultants, the queue would be too long but for 8 consultants there would no queue at all and would probably be very hard for the bank to employ 8 consultants. And the coffee machine usage is definitely way higher when there are less consultants, so in those cases 3 coffee machines would be more optimal than one.

5.1.3 Experiment 4

In this experiment we change number ATMs in order to optimal average number of visitors in queue for ATMs.

Description	ATM Count = 1	ATM Count = 2	ATM Count = 5
Total visitors per day	115.75	107.25	107.67
Reception utilization	0.2304035	0.23611175	0.238474
Reception avg time in queue	165.013 seconds	119.968425 seconds	109.9325567 seconds
Voucher usage	37 requests	34.25 requests	30 requests
Voucher avg utilization	0.034559325	0.0324626	0.027991767
Consultant utilization	1.407905	1.4818575	1.2917467
Consultant avg time in queue	280.1805 seconds	282.70025 seconds	285.959 seconds
Coffee machine usage	1.75 operations	1.5 operations	1.67 operations
Coffee machine avg capacity	0.00324074	0.00277703	0.00308642
ATM machine usage	49.25 enter operations	49 enter operations	55.67 enter operations
ATM avg time in queue	1073.94 seconds	480.426225 seconds	164.343 seconds
Visitors left due to ATM replenishment	5.25 visitors	4.5 visitors	5.67 visitors
Complaint desk usage	23.25 requests	20.5 requests	23 requests
Percentage of invalid documents	23.7225%	20.325%	21.71%
Percentage of successful consultations	62.4875%	67.465%	62.61%
Loan services count	3.75	3.75	3.67
Investment services count	6.75	7.75	5.67
Successfully processed fraud count	0.5	0.25	0.33
Registration count	15.25	16	13.33

Table 4: Comparison of results for different ATM counts.

As we can obviously conclude the more ATMs the less time needed in awaiting a free ATM. This parameter doesn't directly impact other parameters so it is safe to say that 5 ATMs is an ideal number for ATMs as 2 and a half minutes isn't that big of a wait but in the same time 5 ATMs is not that much for a bank.

5.2 Experiment summary

The experiment tested different numbers of consultants, ATMs, and coffee machines to find the best setup. It found that having four consultants, five ATMs and one coffee machine is the right balance, keeping visitors waiting times low while being cost-effective for the bank. It showed that increasing or decreasing these resources too much either led to longer wait times or unnecessary costs. This setup ensures both a good customer experience and efficient use of the bank's budget.

6 Conclusion

As a result of this project we created a simulation model to represent a Bank, created using personal observation of our friends and family members. The result helped us have a deeper understanding of simulation models and their usages and benefits of experimenting with various parameters to enhance, in our case, better experience for customers and overall performance. The final experiment also showed the best way to organize specific aspects of the bank and optimal solution for it so the visitors wouldn't waster much time and the bank wouldn't waster it's resources either for number of ATMs or employees.

References

[1] Martin Hrubý and Petr Peringer. *Modelování a simulace*. 2023. URL: https://www.fit.vutbr.cz/study/courses/IMS/public/prednasky/IMS.pdf.

[2] Petr Peringer. *SIMLIB/C++ == SIMulation LIBrary for C++*. online. 1991. URL: https://www.fit.vut.cz/person/peringer/public/SIMLIB/.