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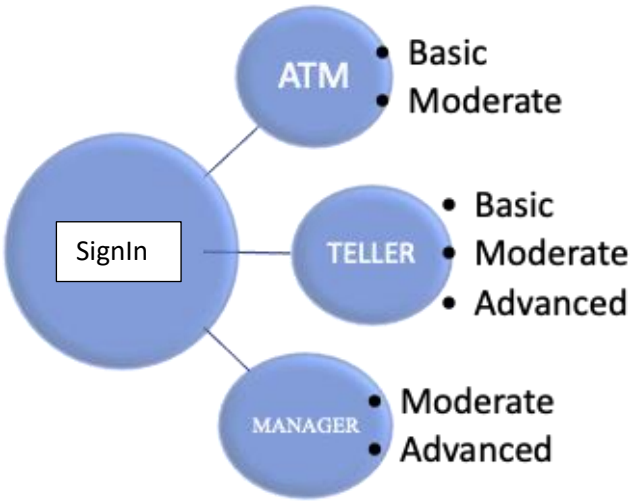
1. **BANK SYSTEM:**

We have a bank system with 3 distinct types of customers. Customers are Basic, Moderate, Advanced with 20%, 50% and 30% customers respectively going to SignIn Station. At SignIn station one bank employee will navigate the customers to ATM, Teller and Manager Station. Below diagram shows distinct types of customers going to 3 distinct types of stations. **Figure 1.1**



SignIn time depends on the customer type. A single queue feeds ATM, Teller, Manager stations. ATM, Teller, manager execution time is independent of the customer type. Customers to the respective stations are on first come and first served basis.

1.1. SYSTEM EXPLANATION:

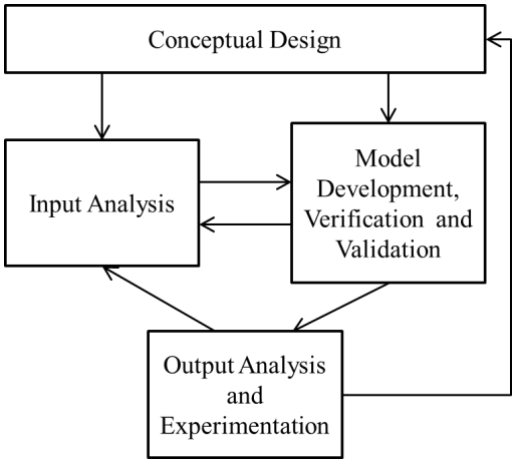
We have modelled bank system with the help of Simulation Process.

Simulation Process: It is an iterative process. It has 4 main parts.

- **Conceptual Design**: It gives the system details of the problem and modeling approaches, outline the system, and plans and models and helps in knowing the simulation software and its capabilities (whether it can do what you need)

- **Input Analysis**: It characterizes the system inputs i.e., random input variables: If the inputs are random, we need to decide their probability distributions and processes, if distribution is exponential, normal, Poisson, etc.
    - Characterizing is done via analyzing the past data on the variable/process. Methodology is developed to generate random observations using these characterizations.
    - Typically, most simulation software has features to generate random observations.
- **Model Development, Verification, and Validation**: This phase converts the conceptual model into an executable simulation model.
    - It carefully builds the model using the software.
    - It also verifies the model is working (some expectations are met)
    - Validation ensures the accuracy of the system.
- **Output Analysis and Experimentation**: This is the final phase. It collects information and analyze the outputs.
    - It also clarifies which metrics are important and collect data accordingly.
    - Characterizes the collected data.
    - It also sets up experiments to investigate different settings.

Below is the flowchart of simulation Process: **Figure 1.2**



The bank system is modelled with the help of **Jackson Network**.

Jackson Network is a queueing network. There are few assumptions with respect to the network.

- All arrival processes from outside have exponential interarrival times (a.k.a. Poisson processes) and are independent of each other.
- All service times are independent exponential (so each node is an *M*/*M*/*c*)
- All queue capacities are infinite.
- Utilization (a.k.a. traffic intensity) *r* locally at each node is < 1.

A Jackson Network is created with the Mean Inter-arrival and Service times calculated from the given data.

The data provided to the system is:

- Stochastic: Data are random inputs to model to represent the realistic variation found in most systems.
- Dynamic: The operations are depending on the time. It is impossible to model the system without time dimension.
- Continuous: State variables can change continuously over time, described by differential equations that are solved numerically.

Below is the Jackson Network of the bank system where:

(Lambda) represents Expected no. of customers arrival per unit time. (Mean arrival rate)

(mu) represents expected no of service completion per unit time. (Mean service rate)

c represents no. of servers.

The weighted average values from SignIn to ATM, Teller, Manager is calculated as follows:

		ATM		**Teller**		**Manager**
Basic	99	67		32		0
Moderate	250	60		122		68
Advanced	151	0		36		115
Total Customers	500					
Weighted value		0.254		0.38		0.366

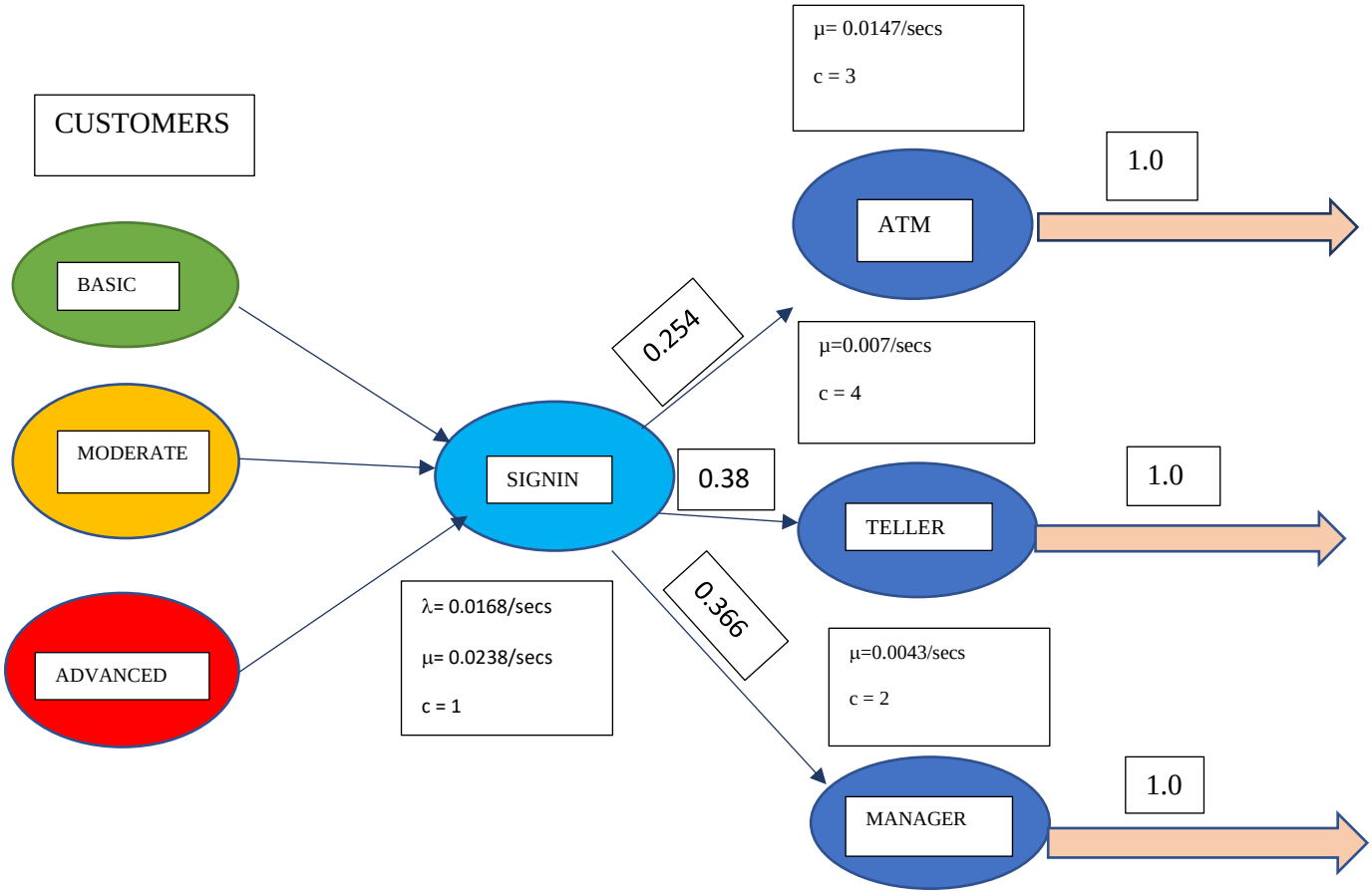


Figure 1.3

Jackson Network

1.2. DATA ANALYSES

We have 500 observations with interarrival time between each customer, Service time for Sign-in station, service times for ATM, Teller and Manager stations. For simulation, we need to find the percentage customers being directed to each station based on customer type and their fitted distributions.

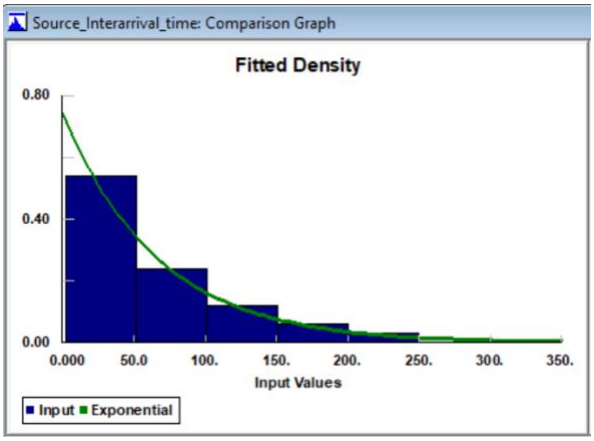
The data given is characterized as: Continuous and Dynamic as it is based on time, Random as the interarrival and service times occur at random intervals. For analyzing the data distribution and to find the mean inter-arrival time and mean service times, we have used Stat:fit to study the first 100 observations from each category of customers. We have used Exponential, Lognormal, Triangular and Uniform distributions to find the fitted distributions as the data give does not contain negative values.

The best fitted distribution for:

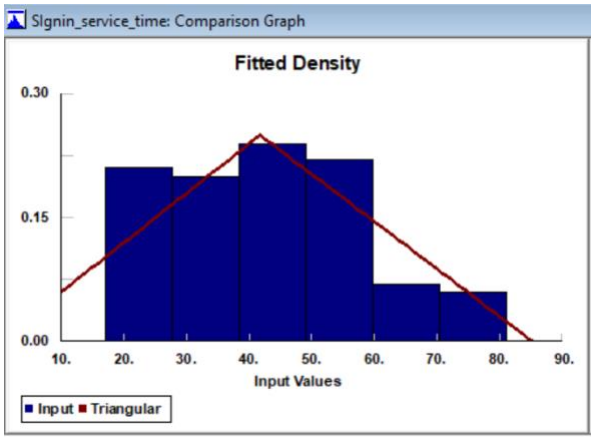
1. Mean interarrival time is Exponential with mean 66.3 (refer Appendix fig.1.2.1) where 20% of Basic, 50% of Moderate and 30% of Advanced customers enter the sign-in station.

2. Mean service time in Sign-in station is Triangular with mean 42.1 (refer Appendix fig.1.2.2) where 25.4% of total customers are directed to ATM station, 38.2% are directed to Teller station and 36.8% are directed to Manager station.
3. Mean service time in ATM station is Exponential with mean 49.4 (refer Appendix fig.1.2.3) where 68% of Basic and 24% of moderate customers are being directed to ATM from the sign-in station.
4. Mean service time in Teller station is Exponential with mean 119 (refer Appendix fig.1.2.4) where 32% of Basic, 49% of moderate and 24% of advanced customers are being directed to Teller from the sign-in station.
5. Mean service time in Manager station is Exponential with mean 234 (refer Appendix fig.1.2.4) where 27% of moderate and 76% of advanced customers are being directed to Manager from the sign-in station.

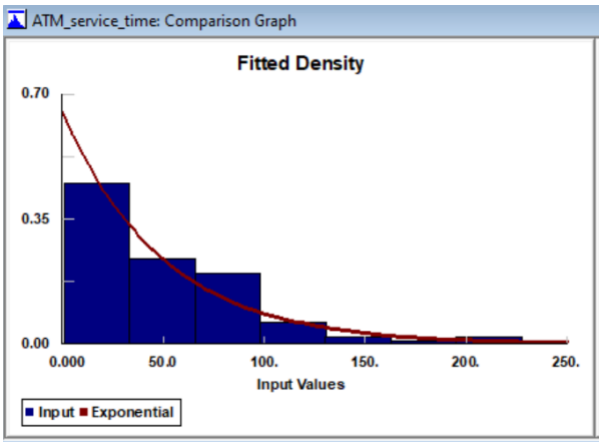
Mean Interarrival time: Exponential (66.3):

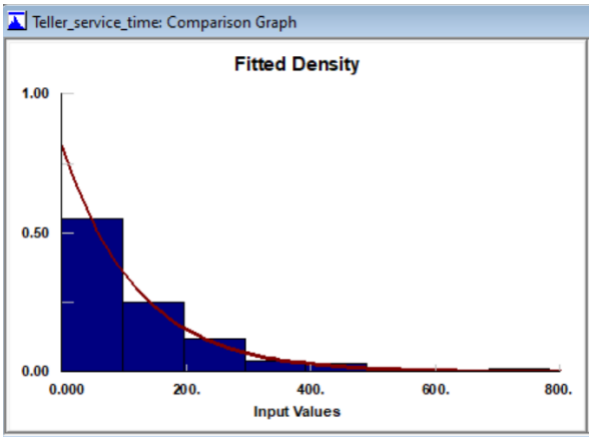


Mean Service Time in Sign-in station: Triangular (0, 85.3, 41.8):

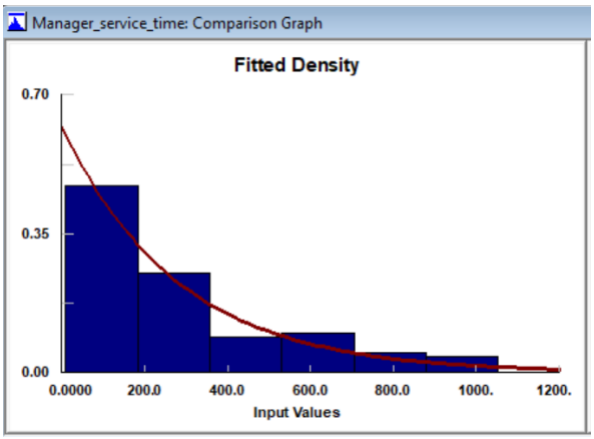


Mean service time in ATM: Exponential (49.4): Mean service time in Teller: Exponential (119):





Mean service time for Manager: Exponential (280)



1.3. SIMIO MODEL AND VERIFICATION

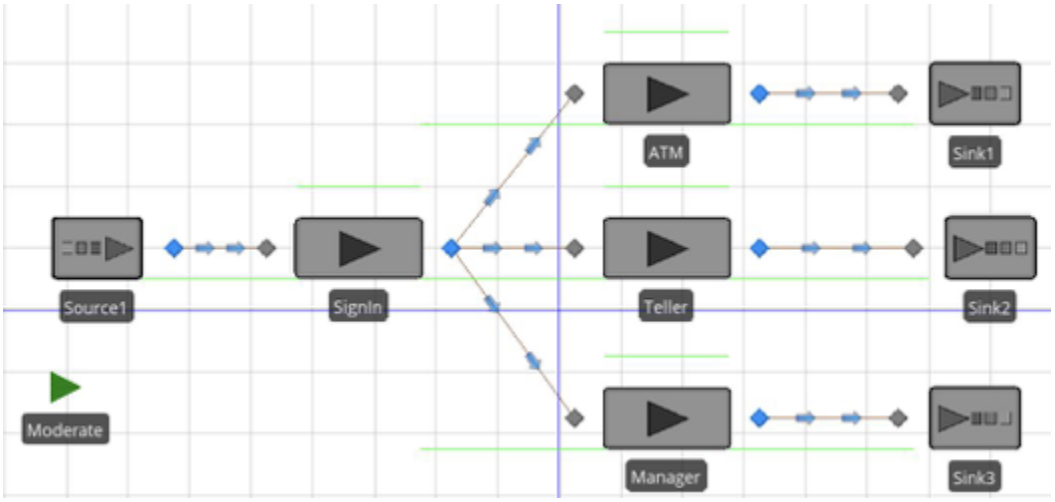
The basic Simio model can be seen in the Appendix, Figure 1. The model is made up of three unique types of customers that enter the system, an individual sign-in station where the customers are directed to the service station that best meets their needs, and 3 service stations. The three types of customers in the system are basic, moderate, and advanced. The three service stations are the ATM stations, Teller stations, and Manager stations. In the model, we used 1 source object with name Source1, 1 model entity named Moderate, 4 server objects for service stations, and 3 sink objects.

Basic customers make up 20% of the total customer base and they can be directed to either the ATM or Teller stations. Moderate customers are the largest customer group at 50% and can be directed to the ATM station, the Teller station, or the Manager station. Advanced customers make

up the final 30% of the customers but they can only be directed to the Teller station or the Manager station.

All employees must initially visit the Sign-in station which is currently staffed by a single employee. The average arrival time between customers at the bank is one customer every 66.3 seconds and the average service time at the Sign-in station is 42.3 seconds. The ATM station is the most basic service station. There are currently three ATM stations, and the average customer spends 49.4 seconds there. The Teller station is currently staffed by four employees with an average service time of 119 seconds (about 2 minutes). The Manager station is currently staffed by two employees and has an average service time of 280 seconds (about 4 and a half minutes).

The verification model for a Jackson Network for moderate type customers is as below: Figure 1.4



Values obtained after simulation run:

With

Run-length = 5000*66.3=331500 sec

Warm-up Period = 500*66.3=33150 sec

Replications = 100

Scenario			Replications		Responses		
	Name	Status	Required	Completed	AverageTimeInQueue...	AverageTimeInSystem...	AverageNumberInSystem
▸	Scenario1	Idle	100	100 of 100	29.0421	214.339	1.615

Table: Comparison of 92-hour Simulation Run and Theoretical Results:

Metric	Queueing	Simulation Run
AverageNumberInSystem (L)	1.585	1.615
AverageTimeInSystem (W)	226.42	214.339
AverageTimeInQueue (W_q)	31.162	29.0421

After comparing Simio and theoretical results, we can conclude that both the results are approximately equal, hence stating our model is verified.

1.4. SYSTEM ISSUES AND ALTERNATIVE ACTIONS

We created three scenarios in our model (Appendix, Figure 2) with each scenario adding employees to the various service stations. Scenario 1 is the current staffing levels, Scenario 2 is the addition of two Sign-in station employees, Scenario 3 is the addition of two employees to the Teller station, and Scenario 4 is the addition of two Managers.

Based on initial run of the current system, we observed that Manager station utilization is large, around 86%, while the Teller station utilization was small, around 50%. To overcome these, two new employees will be hired, and we expected that adding the employees to either the Sign-in or Manager stations would have the greatest impact on reducing the key responses.

The Sign-in station had a utilization of 63% but we thought that reducing the time spent signing in from the modeled time would reduce the response values. This was true but it did not have the expected degree of impact. The utilization at the Sign-in station was reduced to 47%. The key responses were also reduced to an average of 1.95 customers in the bank with average time in the bank of 341 sec and average queueing time of 141 sec.

Scenario 4 had the largest overall impact on the key responses. It reduced the average number of customers in the bank to 1.6 people, the average time in the bank to 279 seconds (about 4 and a half minutes) and the average queueing time to 220 seconds (about 3 and a half minutes). This was entirely attributed to the reduction of the Manager station utilization from 86% to 78%. The

Manager station service time was not reduced but the total time spent queueing at the station went from 6.6 minutes to 0.15 minutes.

2. SIMULATION STUDY

2.1. EXPERIMENT SETUP

We created scenarios by controlling the weight of each type of customer to match the customer mix and ran 100 replications of each scenario. The model used a warmup time of 500 times the interarrival time of 66.3 seconds totaling 33,150 seconds (about 9 hours). The run length of each replication was 5,000 times the average interarrival time totaling 331,500 seconds (about 4 days). We added the responses for each critical factor in the experiment.

These were:

- Average Number in System named AverageNumberInSystem, representing the average number of customers in the bank at any given time.
- Time in System named AverageTimeInSystem, representing the average time a customer spends in the bank once they enter, and Average Holding Time in Station representing the average time a customer spends waiting in the queue while in the bank.
- For the average queueing time named AverageTimeInQueue, we created a weighted average to determine the response because each station has a unique queueing time and customer mix.

Here, We design the experimentation to compare the following four scenarios:

- Scenario 1 – The current situation: Sign-in = 1, ATM = 3, Teller = 4, Manager = 2
- Scenario 2 – Sign-in gets 2 additional servers: Sign-in = 3, Teller = 4, Manager = 2
- Scenario 3 – Teller gets 2 additional servers: Sign-in = 1, Teller = 6, Manager = 2
- Scenario 4 – Manager gets 2 additional servers: Sign-in = 1, Teller = 4, Manager = 4

We defined the following three reference properties:

- First reference property is for Initial Capacity of Sign-in, and it is named as SignIn_InitialCapacity. Its default value is 1.
- Second reference property is for Initial Capacity of Teller, and it is named as Teller_InitialCapacity. Its default value is 4.

- Third reference property is for Initial Capacity of Manager, and it is named as Manager_InitialCapacity. Its default value is 2.

2.2. SIMULATION OUTPUT AND DISCUSSION

The initial run in Scenario 1 gave the baseline results for the key responses. With the current staffing levels, the bank system has 2.4 customers in it on average with each customer spending an average of 421 seconds (about 7 minutes) in the bank and 220 seconds (about 3 and a half minutes) in the various queues. The utilization rate of the stations was 63.7% for the Sign-in station, 50% for the Tellers and 86% for the Managers.

The addition of 2 additional employees in the Teller station in Scenario 3 had the least impact on the system. The response metrics were identical to Scenario 1 with the average number of customers in the bank being 2.39, the average time in the bank was 419 seconds (about 7 minutes) and the average queueing time was 218 seconds (about 3 and a half minutes). This made no significant difference.

Two additional employees at the Sign-in station reduced the values of the key responses but not the degree that Scenario 4 did. The utilization at the Sign-in station was reduced from 63% to 47% and the key responses were reduced to an average of 1.95 customers in the bank with average time in the bank of 341 seconds (about 5 and a half minutes) and average queueing time of 141 seconds (about 2 and a half minutes).

The largest reduction in the responses was by adding the two additional employees to the Manager station. It reduced the average number of customers in the bank to 1.6 people, the average time in the bank to 279 seconds (about 4 and a half minutes) and the average queueing time to 220 seconds (about 3 and a half minutes). This was mostly attributed to the reduction of the Manager station utilization from 86% to 78% and a reduction in queueing at the station from 6.6 minutes to 0.15 minutes. Since the Manager station customers made up 30% of the total customer base, this had the most impact in reducing the responses.

3. CONCLUSIONS

Based on the outcome of our model we concluded that the number of employees at the managerial stations was the most restrictive factor to the desired outcomes of reducing the average number of customers in the bank, reducing the average time customers spend in the bank, and reducing the average time customers spend queuing at the various banking stations. These conclusions resulted in our team recommending that the bank add 2 additional managers to the system to meet the desired outcomes.

As previously stated, the customer mix is 20% basic customers, 50% moderate customers, and 30% advanced customers. However, the advanced customers had the longest service times of all the customers and the utilization rate of the managers while helping customers is 86%.

The addition of two managers, Scenario 4 in our simulation, resulted in the lowest average number of customers in the bank (Appendix, Figure 3), the lowest average time each customer spends in the bank (Appendix, Figure 4), and the lowest average time customers spend in the various station queues waiting for service (Appendix, Figure 5). The addition of employees at the Sign-in and Teller stations reduced the utilization for those stations specifically but had minimal impact on the entire system. The addition of two employees at the Manager station reduced the utilization of the Manager station employees from 86% in all other scenarios to 78% in scenario 4. Additionally, it reduced the queueing time for employees at the Manager station which was the largest contributor to the queueing time being higher in scenarios 1-3.

4. APPENDIX

Fig. 1 – Basic Simio Model

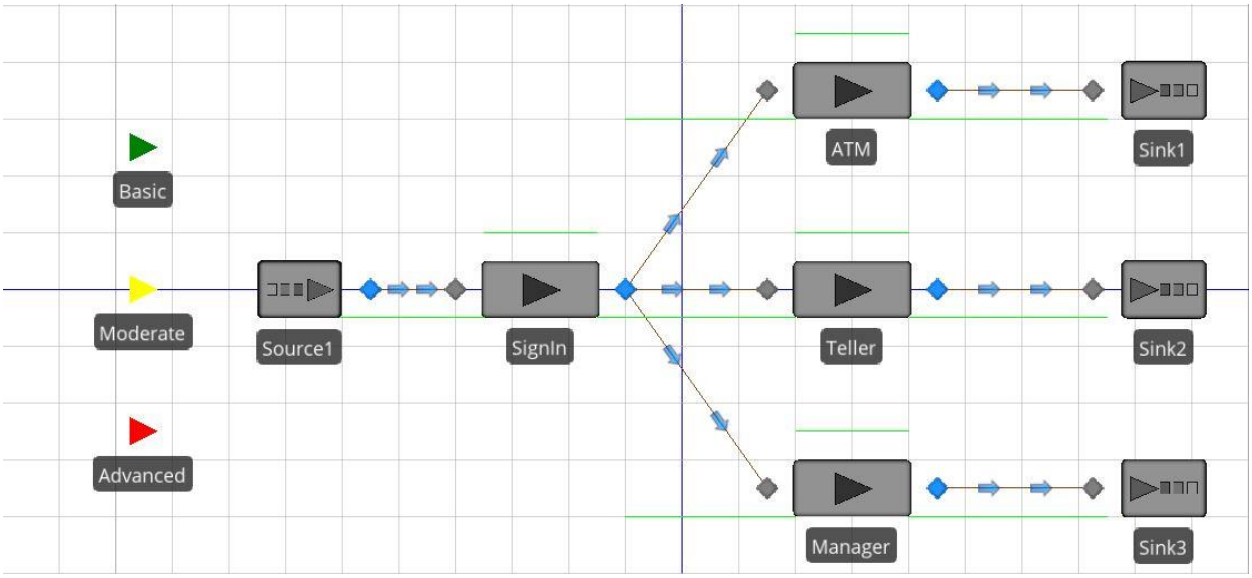


Fig. 2 – Simio Model Scenarios

Design | Response Results | Pivot Grid | Reports | Input Analysis

Scenario			Replications		Controls			Responses		
	Name	Status	Required	Completed	SignIn_InitialCapa...	Teller_InitialCapa...	Manager_InitialCapacity	AverageNumInSy...	AverageTimeInSy...	AverageTimeInQ...
▸	Scenario1	Idle	100	100 of 100	1	4	2	2.38955	475.253	249.848
	Scenario2	Idle	100	100 of 100	3	4	2	2.06707	411.594	186.221
	Scenario3	Idle	100	100 of 100	1	6	2	2.39324	475.777	250.462
	Scenario4	Idle	100	100 of 100	1	4	4	1.44553	285.314	58.2438

Fig. 3 – Avg. Number of Customers in the Bank

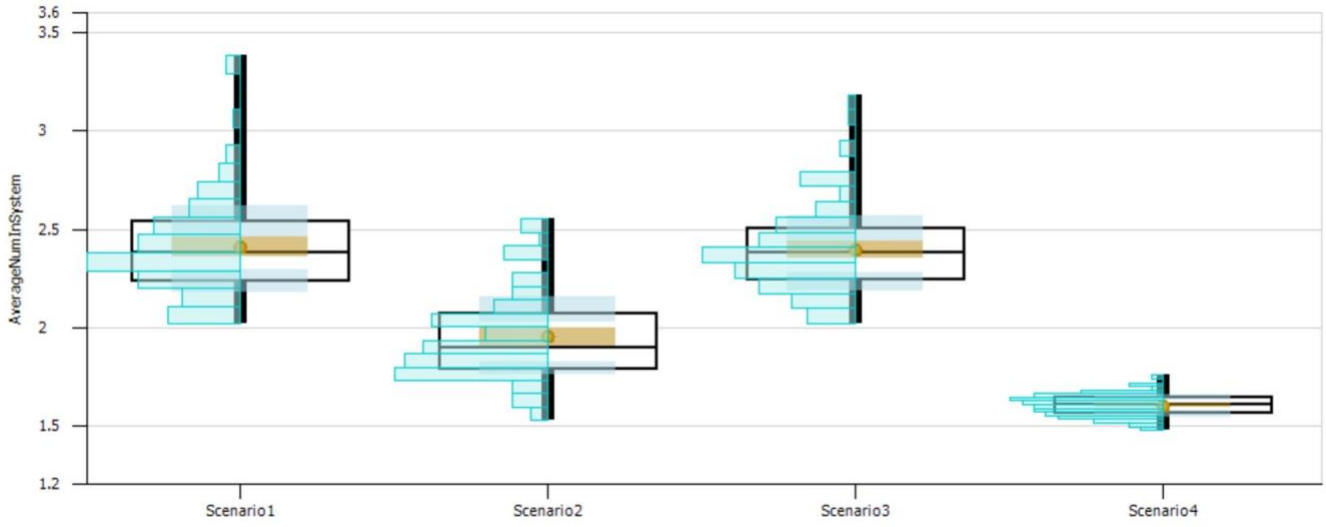


Fig. 4 – Avg. Time Customers Spend in the Bank

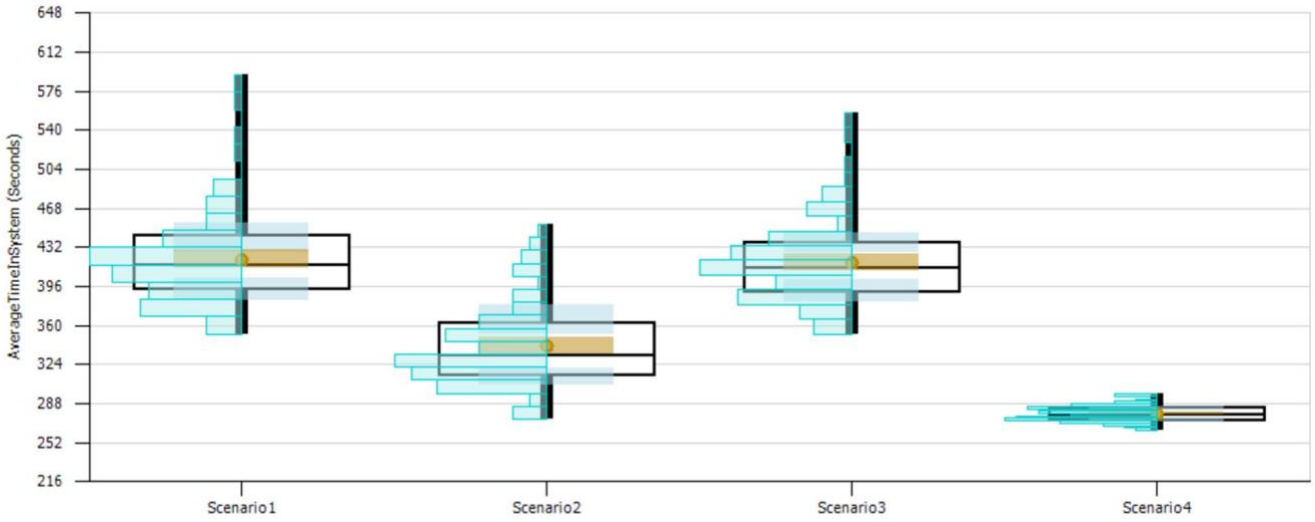


Fig. 5 – Avg. Time Queueing in the Bank