YEDİTEPE UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF INDUSTRIAL ENGINEERING

ISE344 SIMULATION PROJECT

BARBERSHOP QUEUE OPTIMIZATION

TEAM MEMBERS

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1. INTRODUCTION

In the realm of Simulation lesson, our group has identified a pertinent and common challenge faced by service-oriented businesses, within the context of a barber shop. The issue at hand revolves around the efficiency of the queue management system, which directly impacts customer satisfaction, service delivery, and overall business performance.

Background:

Barber shops traditionally operate on a first-come, first-served basis, with customers waiting in a queue until a barber becomes available. However, inefficiencies in the queue management process or other problems like inefficient tools, insufficient number of employees etc. can lead to longer waiting times, customer dissatisfaction, and potential revenue loss. Factors such as varying service times, walk-in clients, and the unpredictable nature of service demand contribute to the complexity of this challenge.

Objective:

Our primary objective is to optimize the queue management system (it can be include anything to make the process faster like buying a new razor) in the barbershop to enhance overall efficiency, reduce customer waiting times, and improve the utilization of barber resources. By doing so, we aim to create a positive impact on customer experience, staff productivity, and the profitability of the business.

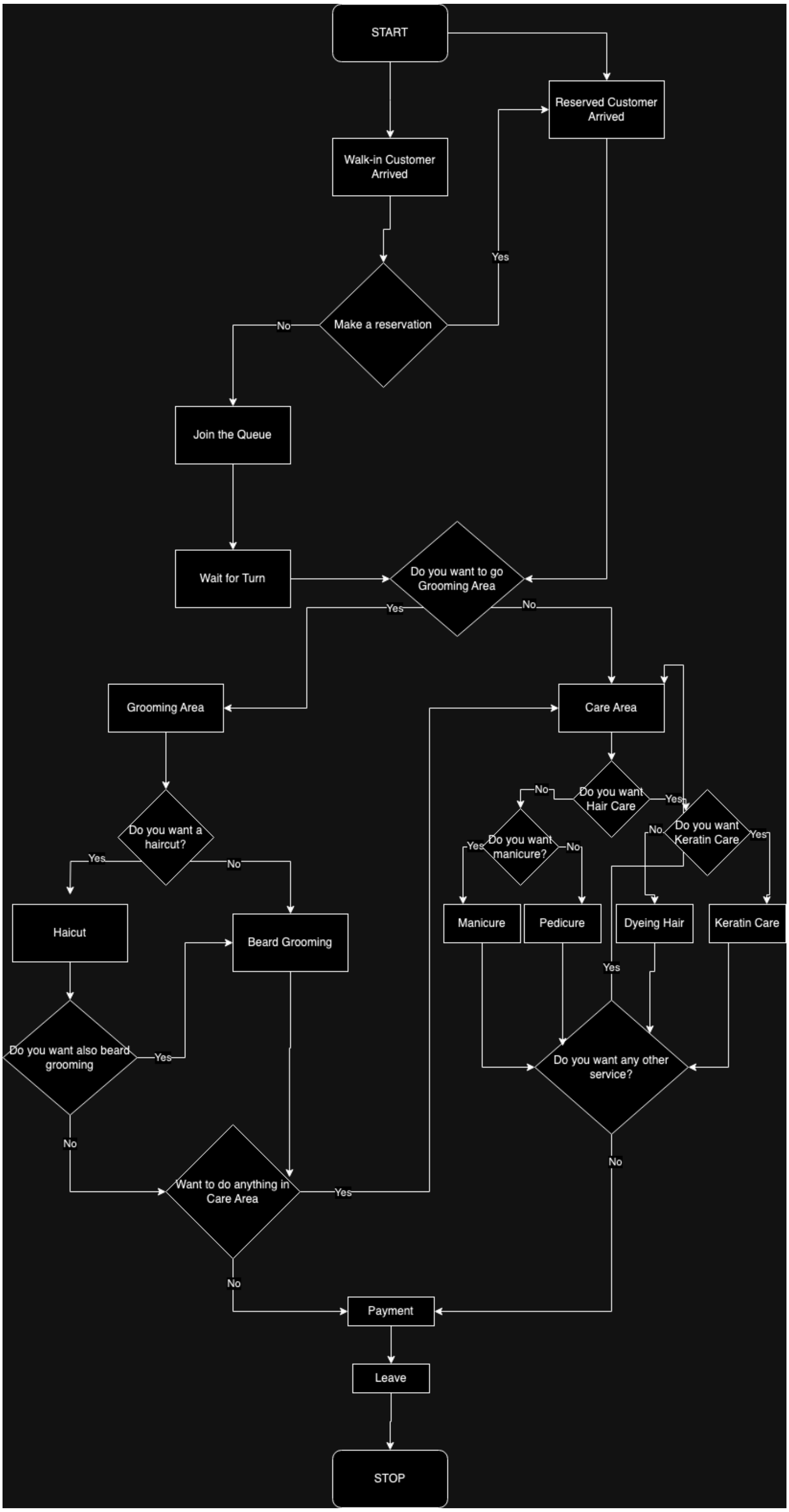
Rationale:

- **Customer Satisfaction:** Long waiting times negatively impact customer satisfaction. By implementing an efficient queue management system, we aim to enhance the overall experience for clients, leading to increased loyalty and positive word-of-mouth.
- **Resource Utilization:** Barbers are a valuable resource, and their time should be utilized optimally. By understanding the dynamics of service demand and improving the scheduling of appointments, we can ensure that barber resources are allocated efficiently.
- **Revenue Optimization:** All businesses want to make more profit. An efficient queue management process can result in increased customer turnover, leading to higher revenue. Additionally, the potential introduction of appointment scheduling may attract more diverse clients, including those with busier schedules.

Expected Outcomes:

- Identification of an optimal queue management strategy that maximizes the profit.
- Increasing customer satisfaction by reducing waiting time. (We accept that there is an increase in customer satisfaction when service time decreases.)
- Recommendations for implementing the proposed changes in the real-world barber shop setting.

Conceptual Design



2. DATA COLLECTION AND INPUT ANALYSIS

INTERARRIVAL TIMES			INTERARRIVALS TIMES		
#	Minute	Hour	#	Minute	Hour
1	60	1,00	31	12	0,20
2	22	0,37	32	10	0,17
3	21	0,35	33	15	0,25
4	60	1,00	34	15	0,25
5	60	1,00	35	19	0,32
6	30	0,50	36	60	1,00
7	19	0,32	37	0	0,00
8	0	0,00	38	34	0,57
9	27	0,45	39	21	0,35
10	43	0,72	40	22	0,37
11	9	0,15	41	0	0,00
12	31	0,52	42	19	0,32
13	57	0,95	43	34	0,57
14	28	0,47	44	12	0,20
15	22	0,37	45	25	0,42
16	0	0,00	46	49	0,82
17	22	0,37	47	16	0,27
18	60	1,00	48	12	0,20
19	16	0,27	49	0	0,00
20	15	0,25	50	19	0,32
21	64	1,07	51	34	0,57
22	0	0,00	52	19	0,32
23	52	0,87	53	34	0,57
24	16	0,27		AVERAGE	0,42
25	21	0,35			
26	63	1,05			
27	31	0,52			
28	0	0,00			
29	0	0,00			
30	13	0,22			

	SERVICE TIME (Hours)					
	Haircut	Beard	Manicure	Pedicure	DyeinHair	Keratin
	0,97	0,20	0,30	0,22	0,40	0,23
	0,67	0,12	0,25	0,25	0,30	0,25
	0,73	0,20	0,28	0,22	0,48	0,28
	0,82	0,15	0,20	0,20	0,38	0,18
	0,87	0,17	0,20	0,20	0,40	0,20
	0,53	0,12	0,23	0,27	0,32	0,28
	0,87	0,18	0,30	0,27	0,40	0,33
	0,87	0,18	0,22	0,25	0,38	0,27
	0,97	0,18	0,28	0,25	0,50	0,22
	1,05	0,22	0,28	0,27	0,33	0,20
	1,02	0,22	0,20	0,28	0,38	0,30
	0,58	0,15	0,28	0,27	0,25	0,25
	0,87	0,22	0,30	0,23	0,38	0,23
	0,52	0,22	0,25	0,28	0,45	0,22
	0,82	0,22	0,23	0,30	0,38	0,23
	1,03	0,08	0,23	0,27	0,25	0,18
	0,73	0,10	0,22	0,27	0,28	0,23
	0,80	0,17	0,22	0,25	0,28	0,27
	0,80	0,10	0,20	0,30	0,30	0,32
	0,67	0,08	0,22	0,28	0,25	0,18
	0,67	0,13	0,25	0,22	0,25	0,28
	0,55	0,20	0,23	0,22	0,48	0,27
	0,62	0,12	0,25	0,22	0,30	0,23
	0,98	0,15	0,30	0,25	0,38	0,20
	1,03	0,12	0,28	0,23	0,30	0,33
	0,90	0,15	0,25	0,27	0,35	0,27
	0,73	0,13	0,25	0,28	0,43	0,25
	1,03	0,20	0,27	0,22	0,45	0,18
	0,93	0,17	0,30	0,25	0,43	0,22
	0,80	0,13	0,23	0,22	0,38	0,33
	0,80	0,08	0,23	0,22	0,38	0,27
AVERAGE	0,81	0,16	0,25	0,25	0,36	0,25

PROBABILITIES		
HAİR	BEARD	CARE AREA
0.7	0.5	0.2
If a customer goes to Care Area it is equally likely to go manicure, pedicure, hair dyeing or keratin care.(0.05 each)		

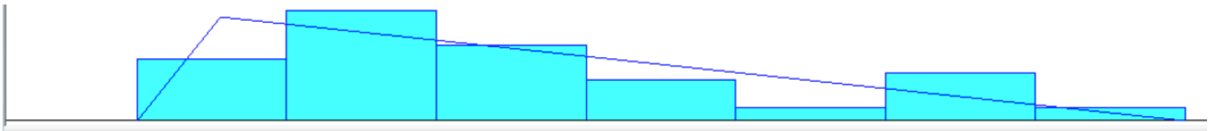
The "Probabilites" dataset is the historical Data about when a customer steps in the shop what is the probability of taking a service, we get the historical data from the owner of the barber shop.

Scheduled Customer Total Time(Hours)									
0.8	0.92	0.78	0.9	1.01	0.68	0.87	1.25	0.91	0.8
1.03	0.85	1	1.2	0.9	0.85	0.92	1.1	1.02	0.84
0.75	0.96	1.3	0.88	0.98	1.05	0.73	0.9	1.15	0.97
0.88	1.03	1.1	1.05	0.72	0.91	0.98	0.81	0.92	1.1
1.28	1.08	0.96	1.3	0.88	1.16	1.05	0.9	0.77	0.82

Walk-In Customer VA Time				
0.54	0.87	0.79	0.94	0.82
0.85	0.96	0.91	0.79	0.73
0.69	0.7	0.88	0.6	0.67
0.7	0.74	0.55	0.61	0.64
0.75	0.7	0.63	0.39	0.72
0.48	0.83	0.85	0.48	0.68
0.55	0.63	0.55	0.74	0.46
0.69	0.67	0.8	0.65	0.53
0.66	0.72	0.79	0.58	0.62
0.81	0.68	0.55	0.56	0.87

	Sample Schedule from a day of working		
Time	**Hairdresser1**	**Hairdresser2**	**Care Area Worker**
9am	0	0	0
10am	0	1	0
11am	0	0	0
12pm	1	1	0
1pm	1	0	0
2pm	1	0	1
3pm	0	0	0
4pm	1	1	0
5pm	1	1	0
6pm	1	1	1
7pm	0	1	0
8pm	0	1	0
9pm	0	0	0

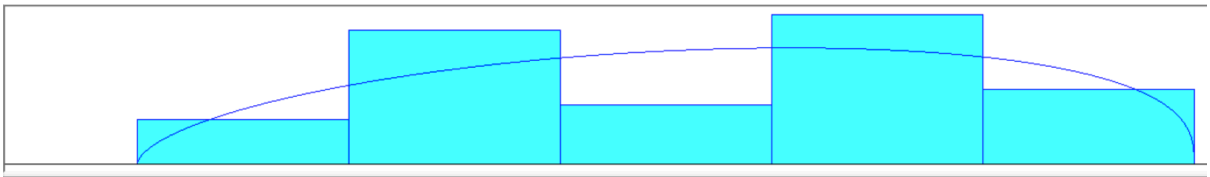
Input Analysis



```
        Distribution Summary

Distribution:   Triangular
Expression:     TRIA(-0.001, 0.0929, 1.18)
Square Error:   0.016106

Chi Square Test
  Number of intervals   = 5
  Degrees of freedom    = 3
  Test Statistic        = 4.19
  Corresponding p-value = 0.244

Kolmogorov-Smirnov Test
  Test Statistic        = 0.11
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 53
Min Data Value          = 0
Max Data Value          = 1.07
Sample Mean             = 0.424
Sample Std Dev          = 0.32

        Histogram Summary

Histogram Range         = -0.001 to 1.18
Number of Intervals     = 7
```

Inter Arrival Times

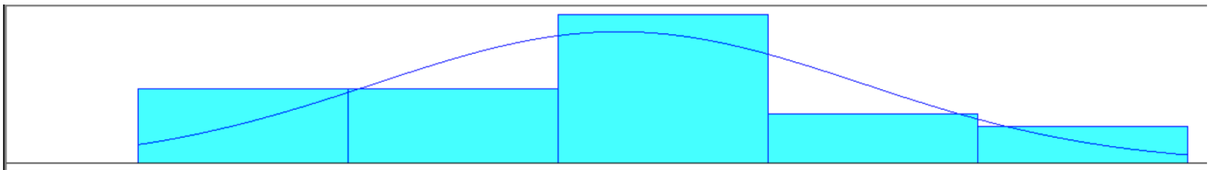
Square Error < 0.05
Corresponding p-value from Kolmogorov-Smirnov > 0.15
So, the distrubition is a good fit for us.



```
        Distribution Summary

Distribution:   Beta
Expression:     0.06 + 0.18 * BETA(1.58, 1.35)
Square Error:   0.027056

Chi Square Test
  Number of intervals   = 4
  Degrees of freedom    = 1
  Test Statistic        = 2.97
  Corresponding p-value = 0.0885

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0807
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 31
Min Data Value          = 0.08
Max Data Value          = 0.22
Sample Mean             = 0.157
Sample Std Dev          = 0.0453

        Histogram Summary

Histogram Range         = 0.06 to 0.24
Number of Intervals     = 5
```

Service Time for Beard Cut

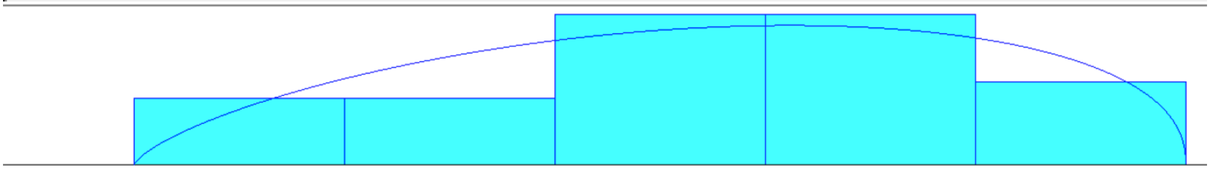
Square Error < 0.05
Corresponding p-value from Kolmogorov-Smirnov > 0.15
So, the distrubition is a good fit for us.



```
        Distribution Summary

Distribution:   Normal
Expression:     NORM(0.362, 0.072)
Square Error:   0.022528

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 0
  Test Statistic        = 1.26
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.177
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 31
Min Data Value          = 0.25
Max Data Value          = 0.5
Sample Mean             = 0.362
Sample Std Dev          = 0.0731

        Histogram Summary

Histogram Range         = 0.22 to 0.53
Number of Intervals     = 5
```

Service Time for Hair Dyeing

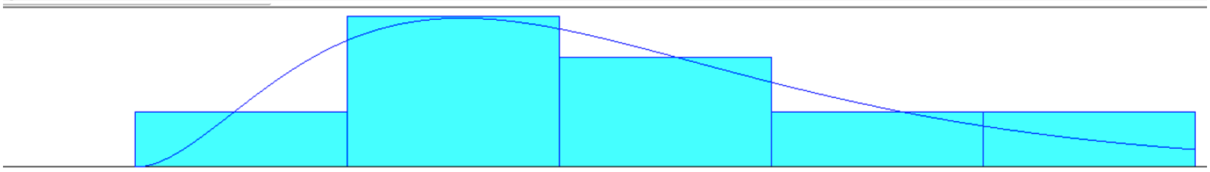
Square Error < 0.05
Corresponding p-value from Kolmogorov-Smirnov > 0.15
So, the distrubition is a good fit for us.



```
        Distribution Summary

Distribution:   Beta
Expression:     0.46 + 0.65 * BETA(1.7, 1.43)
Square Error:   0.009241

Chi Square Test
  Number of intervals   = 4
  Degrees of freedom    = 1
  Test Statistic        = 0.562
  Corresponding p-value = 0.469

Kolmogorov-Smirnov Test
  Test Statistic        = 0.111
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 31
Min Data Value          = 0.52
Max Data Value          = 1.05
Sample Mean             = 0.814
Sample Std Dev          = 0.159

        Histogram Summary

Histogram Range         = 0.46 to 1.11
Number of Intervals     = 5
```

Service Time for Haircut

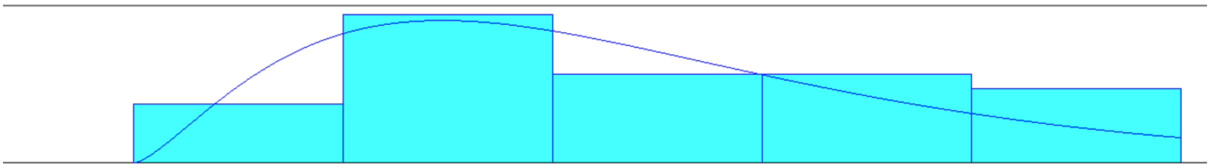
Square Error < 0.05
Corresponding p-value from Kolmogorov-Smirnov > 0.15
So, the distrubition is a good fit for us.



```
        Distribution Summary

Distribution:   Erlang
Expression:     0.16 + ERLA(0.0292, 3)
Square Error:   0.004737

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 0
  Test Statistic        = 0.343
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.144
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 31
Min Data Value          = 0.18
Max Data Value          = 0.33
Sample Mean             = 0.248
Sample Std Dev          = 0.0458

        Histogram Summary

Histogram Range         = 0.16 to 0.35
Number of Intervals     = 5
```

Service Time for Keratin Care

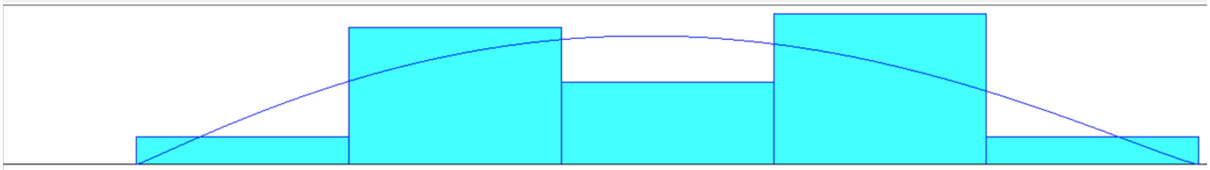
Square Error < 0.05
Corresponding p-value from Kolmogorov-Smirnov > 0.15
So, the distrubition is a good fit for us.



```
        Distribution Summary

Distribution:   Gamma
Expression:     0.19 + GAMM(0.024, 2.47)
Square Error:   0.012286

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 0
  Test Statistic        = 2.53
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.141
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 31
Min Data Value          = 0.2
Max Data Value          = 0.3
Sample Mean             = 0.249
Sample Std Dev          = 0.0334

        Histogram Summary

Histogram Range         = 0.19 to 0.31
Number of Intervals     = 5
```

Service Time for Manicure

Square Error < 0.05
Corresponding p-value from Kolmogorov-Smirnov > 0.15
So, the distrubition is a good fit for us.

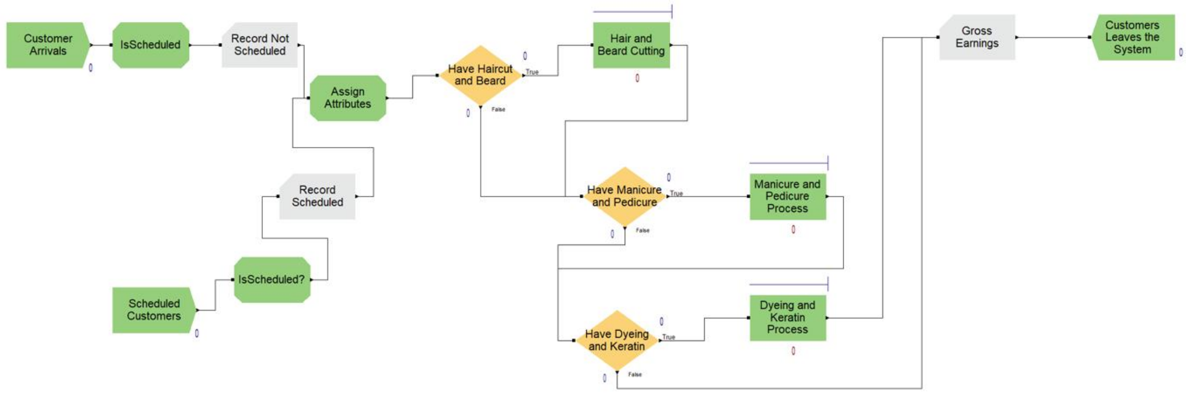


```
        Distribution Summary

Distribution:   Beta
Expression:     0.19 + 0.12 * BETA(2.06, 2.15)
Square Error:   0.031677

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 0
  Test Statistic        = 3.9
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.169
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 31
Min Data Value          = 0.2
Max Data Value          = 0.3
Sample Mean             = 0.249
Sample Std Dev          = 0.0285

        Histogram Summary

Histogram Range         = 0.19 to 0.31
Number of Intervals     = 5
```

Service Time for Pedicure

Square Error < 0.05
Corresponding p-value from Kolmogorov-Smirnov > 0.15
So, the distrubition is a good fit for us.

3. SIMULATION MODEL



We have 2 input(Customer) generation model:

1- Walk-in Customers ("Customer Arrivals" in arena model)
   a. İmplemented by the statistical distribution of interarrival time data
   b. Assigned "ScheduledCustomer" attribute as 0.
2- Scheduled Customers ("Sheduled Customer" in arena model)
   a. İmplemented by the Schedule that we get from the barber shop, "sample schedule from a day of working" data.
   b. Assigned "ScheduledCustomer" attribute as 1.

- The "ScheduledCustomer" attribute assigned because the arena model should prioritize the scheduled customer, model does it due to highest attribute value of assigned attribute.

In the "Assign Attributes" part of the model, the attributes are assigned to BeardCut, Haircut, Manicure, Pedicure, Dyeing, and Keratin services as 1 if the service will be used, 0 otherwise. This assignment occurs due to "Probabilities" data, which is a set of historical data that we gather from the barbershop's owner.

In the decision parts of the model:

$$if\ BeardCut + Haircut \geq 1\ returns\ True, \qquad else\ returns\ False.$$

$$if\ \ Pedicure + Manicure\ \ \geq 1\ returns\ True, \qquad else\ returns\ False$$

$$if\ Dyeing + Keratin \geq 1\ returns\ True, \qquad else\ returnsFalse$$

Equations are used because beard and hair cutting, pedicure and manicure, dyeing a hair and keratin events take place without the customer getting up from their seats, but for example, someone who wants to get a manicure after a haircut must get up and change seats.

For the process part of the model:

$$Haircut * \left(0.46 + 65 * BETA(1.7{,}1.43)\right) + BeardCut(0.06 + 0.18 * BETA(1.58{,}1.35))$$

$$Manicure * \left(0.19 + GAMM(0.024{,}2.47)\right) + Pedicure * (0.19 + 0.12 * BETA(2.06{,}2.15))$$

$$Keratin * \left(0.16 + ERLA(0.0292{,}3)\right) + Dyeing\left(NORM(0.362, 0.72)\right)$$

Equations are used. if the customer does not use a service it will be zero because the service attribute will be zero due to the "Assign Attributes" part, the statistical distributions are the distributions that found with input analysis.

- The fixed capacities are specified in the model.

Worker's Area	Capacity
Cutting Area	2
Care Care	1

After all processes are finished the model counts the Gross Earnings.

$$\sum_{service} (Price\ of\ the\ service) * (Service)$$

Then customer leaves the system.

4. VERIFICATION AND VALIDATION

Verification and Validation

VALUE ADDED TIME

Replication		(Y2) Walk-In VA Time(hours)	
1		0,6439	
2		0,5855	
3		0,5877	
4		0,6643	
5		0,7032	
6		0,8053	
7		0,5439	
8		0,696	
9		0,6914	
10		0,6662	
	Sample Mean	0,65874	
	Standard Deviation	0,074399301	
	alpha	0,05	
	μ0	0,692	
HYPOTHESIS TESTING			
	H0: E(Y2)=0.692 hours		
	H1: E(Y2)≠0.692 hours		
t0	**1,869**		
tcritical	**2,262**		
tc>t0	**Do not Reject H0**		
TYPE II ERROR			
Ɛ	0,1		
Ɛ / S	1,344098648		
ß(1.34)	0,1		
Power	0,9		
C.I TESTING			
LCL	0,605521644	Worst Case	0,0864784
UCL	0,711958356	Best Case	0,0199584
Worst Case < Ɛ (0.1) --> Accept the model			

TOTAL-TIME (SCHEDULED CUSTOMER)

Replication		(Y2) Scheduled Total Time(hours)	
1		0,8559	
2		1,0853	
3		1,0372	
4		0,9425	
5		0,9779	
6		0,8625	
7		0,938	
8		0,7365	
9		0,9641	
10		0,9388	
	Sample Mean	0,93387	
	Standard Deviation	0,098152026	
	alpha	0,05	
	μ0	0,96	
HYPOTHESIS TESTING			
	H0: E(Y2)=0.96 hours		
	H1: E(Y2)≠0.96 hours		
t0	**0,841786602**		
tcritical	**2,262**		
tc>t0	**Do not Reject H0**		
TYPE II ERROR			
Ɛ	0,1		
Ɛ / S	1,018827676		
ß(1.02)	0,2		
Power	0,8		
C.I TESTING			
LCL	0,868591149	Worst Case	0,0914089
UCL	1,009008851	Best Case	0,0490089
Worst Case < Ɛ (0.1) --> Accept the model			

In the validation and verification of the simulation model, historical data means were utilized for comparison with the simulation outputs through a t-test, which ultimately concluded that there is no significant difference, affirming the model's adequacy. Additionally, a power analysis for Type II error indicated sufficiently high power levels at 90% and 80%, minimizing the risk of overlooking significant differences. Confidence interval testing further supported the validation, revealing that the simulation and real system data are close enough as the confidence interval contains the hypothesis mean (µ0). The decision rule, considering worst-case error bounds, the model is accepted worst-case error is <-error. In conclusion, our methodology, which includes hypothesis testing, power analysis, and confidence interval testing, strongly supports the validity of our simulation model with no identified reasons for its invalidation.

5. OUTPUT ANALYSIS

OUTPUT ANALYSIS

CI ESTIMATION

R_0	5
S_0^2	0,021676095
ε	0,1
$(Z_{0.025} \cdot S_0 / \varepsilon)^2$	8,327088751

	Y_i	$(Y_i - \bar{Y})^2$
1	0,8559	0,0060793
2	1,0853	0,022931
3	1,0372	0,0106771
4	0,9425	7,448E-05
5	0,9779	0,0019386
6	0,8625	0,0050937
7	0,938	1,706E-05
8	0,7365	0,0389549
9	0,9641	0,0009139
10	0,9388	2,43E-05

R	9	10	11
$t_{0.025,\,R-1}$	2,306	2,262	2,228
$(t_{0.025,\,R-1} \cdot S_0 / \varepsilon)^2$	11,52655844	11,090886	10,759979

$\bar{Y}$	0,93387
$\sum(Y_i - \bar{Y})^2$	0,0867044

R = 11 is the smallest integer satisfying the error criterion, so R-R0 = 6 replication needed.

	Confidance Interval	(0.86, 1.00)	Prediction Interval	(0.71, 1.16)	
LCL	0,864716454		0,7054634		PI > CI
UCL	1,003023546		1,1622766		PI is wider than CI

In a statistical sampling scenario, an initial sample of size $R0$=5 was taken, yielding an initial estimate of the population variance $S0$^2=0.0216. The desired final sample size, guided by an error criterion ε=0.1 and a confidence coefficient $1-\alpha$=0.95, was determined to be 8.32~9. Resulting in a total of R is 11, this necessitates an additional 6 replications beyond the initial 5. Notably, the prediction interval for individual observations is expected to be wider than the confidence interval for the mean, reflecting the inherent variability in both individual data points and the sample mean.

6. COMPARISON OF ALTERNATIVES

Comparison of Current Model And Alternative Model

	Y1	Y2		Y1-Y2(D)	(D - D_avg)^2
Replication	Current Model	Alternative Model		-3300.00	640000.00
1	14750.00	18050.00		-3700.00	1440000.00
2	11950.00	15650.00		-800.00	2890000.00
3	13900.00	14700.00		-500.00	4000000.00
4	11200.00	11700.00		-4550.00	4202500.00
5	12700.00	17250.00		-2000.00	250000.00
6	14450.00	16450.00		-3200.00	490000.00
7	9850.00	13050.00		-3800.00	1690000.00
8	12850.00	16650.00		-2650.00	22500.00
9	13250.00	15900.00		-500.00	4000000.00
10	13600.00	14100.00	**Total**	**-25000.00**	**19625000**
Mean	**12850**	**15350**	**Avg. (D_avg)**	**-2500**	
Std. Dev	**1511.070261**	**1966.101614**	**Sd**	**1476.670429**	

tcritical	**2.262**	**C.I for**	**θ1-θ2 (-3556.273 , -1443.727)**
s.e.(Y1-Y2)	**466.9641909**	**L.I**	**-3556**
		H.I	**-1444**

Note: If c.i. is totally to the left of 0, strong evidence for the hypothesis that θ1 − θ2 < 0 (θ1 < θ2).

We increased our hairdresser capacity from 2 to 3 to the model we offered as an alternative and compared the Gross earnings of the alternative model and the current model. we found that θ1 < θ2 and zero is not in the interval so this is strong evidence that our alternative model is better than the current model.

7. CONCLUSIONS

When we started the project, our main objective was to maximize the profit of the barbershop with queue optimization. To do that, we gathered data, made a simulation model that was similar to real life, made statistical tests, evaluated the results, and decided that we had to hire a new hairdresser to make more profit. After we made the output analysis to compare the current system's and the alternative system's profits, which have three hairdresser capacities, we saw that we had strong evidence to accept the alternative model. In our barbershop, when a barber gives a service, he earns half of it, and the owner earns the other half. Gross earnings increase by an average of 2500 Turkish Liras, which means 1250 Turkish Liras more profit per day can be made, which is equal to 37500 more profit per month. That shows that we can implement our alternative model in real life to have a better business.

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