Redesigning the Repair Network of Toner it Down! Inc.

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I. Executive Summary

Toner It Down! Inc. has been a competitive developer and manufacturer of high-tech document management equipment and systems. Among its three divisions, the repair division is in charge of the follow-up support work of already-sold products. The customer service that handles repair requests from customers plays a significant role in whether current customers want to stay loyal to TIDInc. The main subject of concern is whether TIDInc. is able to provide this repair service in a timely manner for the business centers in the Syracuse area. The repair division needed assistance improving its current repair network and support system. Competitors were able to provide supply and support to their customers in less time than TIDInc could, and it was unlikely that the company would be able to keep its customer base with the current process of responding to a customer repair request. After discussing with managers, the two key performance measures decided upon were initial response time and delivery time for replaced copiers.

The initial response time is the time frame between the time of a customer request call and the time of arrival of a mechanic at the customer's location. This time is highly dependent on the number of mechanics TIDInc employs, as a mechanic cannot transfer to another business center until on-site diagnosis and repair (if needed) are completed. The delivery time for replaced copiers, only collected for requests requiring off-site repair, indicates the time interval between the customer request call and the completion of installing a functional copier at the business center. The flexibility of this replacement time depends on the number of vans available, as a van can only carry one copier at a time and must always go back to the dispatch center to receive a functional copier. Other measures, such as the on-site diagnosis times and on-site repair times were deemed not reducible as managers believed the mechanics were trying their best. With these two performance metrics in mind, it was important to also consider the numerous constraints and factors that were not flexible in the system.

To simulate the current TIDInc. repair network in the Syracuse area, a model was built in the Simio software. There are seven general key components to the Simio model to note. Firstly, the source was where call requests were received, and the dispatch center was modeled as a node where all of the mechanics and vans were situated initially. The ten business centers in the area that TIDInc. were responsible for were modeled as servers in the system. These components were connected with connectors and paths to represent roads and the transfer of requests through the system. The two resources, mechanics and vans, were modeled as worker and vehicle, respectively. Lastly, two sinks represented the two ways in which requests will leave TIDInc's call system - one through on-site repair only, where only a mechanic was met at the business center, and the other through off-site repair, where the request leaves after the successful installation of a functional copier.

The main objective was to lower initial response time to less than one hour and lower the delivery time for replaced copiers to within three hours in order to do better than the competition, while keeping the total cost of the process, mainly the costs of the resources, mechanics and vans, as minimized as possible. After building the model with all of the variables that will remain constant, such as road lengths, speed limits, van capacity, and then testing different combinations of the number of mechanics and vans, it was found that eight mechanics and four vans produced the optimal result. The initial diagnosis time would be on average 0.776173 hours, and the copier replacement time would be 2.91565 hours, less than the average of one hour and three hours of nearby competitors. With this combination of resources, TIDInc. will be able to not only keep up with the competition, but also not have excess costs. The goal is to perform better than the competition, but not spend excessive amounts to achieve this goal.

Our team recommends TIDInc. to spend a total of $1.52 million for the repair division to be able to retain its current customer base and possibly attain more. In order to stay competitive in this market, the follow-up support after equipment has already been sold is critical. Although the costs may seem high, with the current constraints and fixed unit costs of $140,000 for one mechanic and $100,000 for one van, reducing costs below $1.52 million will result in insufficient resources to keep TIDInc's initial diagnosis times and delivery times for replaced copiers competitive in Syracuse. This model will reliably achieve TIDInc's performance goals, while keeping its economic goals in mind.

II. Problem Description

The management was unsatisfied with the repair division's current performance. The company has suffered from a loss in revenue and loyal clients due to slower service times compared to its competitors. Our team has been tasked to find a solution to this problem by the means of simulation. When developing a model to represent the current network, our key goal was to minimize the initial response time of mechanics and the delivery time for replaced copiers. This would lead to quicker solutions to clients' requests, which in turn would satisfy customers and increase revenue.

Currently, competitors of TIDInc. are able to on average, have a mechanic reach the customer location less than an hour after the call. In addition, in cases where the copier needs to be replaced, competitors seem to provide the customer with a working copier within three hours on average. Our task was to create a renovated repair network that provides responses and replacements that were at least as efficient as TIDInc's competitors. An important factor to consider was the costs for mechanics and vans while modeling, as the managers wanted to perform better than competitors without spending unnecessary, unrestrained costs. With all this in consideration, our team will try to improve the current network model to find the optimal number of resources that the repair division's management should invest in.

III. Modeling Approach and Assumptions

This simulation model was built with seven key components: one ModelEntity to represent the requests, two ModelEntity.Picture to represent offsite repairs and onsite repairs, one source called requestcenter, a node called dispatchnode, ten servers for each business center, a worker to represent the mechanic resource, a vehicle to represent the van resource, two sinks called fix and vanfix, and numerous connectors and paths to link different parts of the system. The model was built in Simio software.

Requests arrive to the source according to piecewise rates by the hour, for which a rate table in Simio was created. The rates are computed during our team's data analysis of the customer request arrival data that TIDInc. had collected over the span of 60 days. The methodology of this data analysis is further discussed in detail in Section IV. Data Analysis. The arrival of requests at the source are separated by assigning a state variable “Business” to indicate the origin of each request, based on the estimated fraction of calls that originate at each business center. For example, Business has a value of 1 if the repair request came from Business Center 1, a value of 2 if the request is from Business Center 2. The estimated fractions of calls are further discussed in the following section. The request is sent from the source to a business center through connectors. The ten connectors have a logical expression that ensures that a request is sent to the correct business center based on the state assignment “Business” set at the source. For example, if a state assignment of Business had a value of 1, then the request would travel through the connector that had the logical expression of “Business = = 1”.

Once the request reaches the input node of the business center, a state assignment given to the ModelEntity.Picture assign a value of 0, if the request only requires an onsite repair and a value of 1 if the repair cannot be fixed onsite (i.e. needs a van replacement). This state assignment has a value of 0 with a probability of 0.8195 and a value of 1 with a probability of 0.1805. In addition, the mechanic is included as a secondary resource for all business center servers, so that the dispatch node can release the mechanics to be sent to the corresponding business center. The request will only begin processing at the server if the mechanic has actually arrived at the business center.

The arrival of a mechanic at the business center allows the mechanic’s processing time to start. The processing time at the server is set to the format: Math.Abs(Math.IF(ModelEntity.Picture == 0, diagnose time + onsite repair time, diagnose time)). More specifically, the processing time expression is Math.Abs(Math.If(ModelEntity.Picture == 0, Random.Normal(16.13,2.89) + Random.Beta(2.618,7.462),Random.Normal(16.13,2.89)) for business centers 1,4,5,6,7,8, and 10. For business centers 2,3,9, the processing time is Math.Abs(Math.If(ModelEntity.Picture == 0, Random.Normal(22.15,5.35) + Random.Beta(2.618,7.462),Random.Normal(22.15,5.35))). The distributions are further discussed in the next section.

The completion of the mechanic’s jobs indicates that the request is ready to leave the server. Add-on processes were implemented at each business center to determine the next consecutive steps. The add-on process begins with a conditional Decide function that returns True if the ModelEntity.Picture == 1, designating the request as an offsite repair; else False and the request leaves the system, as it only required onsite repair. Therefore, if the Decide function returns False, the request is processed with a Transfer function that leads the request to the “fix” sink. If the Decide function returns True, the Seize event is triggered. Seize will call for the van to be sent from the dispatch node to the input node of the corresponding business center. Once the van arrives, the Delay event is prompted, which represents the swapping time of the printers. The delay is set to have a Triangular distribution with parameters: minimum =20, maximum =60, most likely=30 in minutes. To also account for the swapping time at the dispatch center, the van operator’s dropoff time is set to Triangular(min=10,max=25, most likely=15) minutes. Once the delay, or swapping of copiers, at the business center is completed, the add-on process initiates the Release event, which allows the van to leave the server and return to the dispatch node. After the Release event has been executed, the transfer event is finally triggered so that the offsite request may enter the “vanfix” sink in order to leave the system. To further grasp the details of the add-on process, refer to Appendix D.

The resources vans and mechanics are set to return to their home nodes, the dispatch node, whenever they are idle. However, the add-on process Release function constrains the van operator to always return to the dispatch node before processing any other request. On the contrary, mechanics are set to go between different business centers according to the smallest distance. All paths that connect the repair network of dispatch node and business centers have their appropriately scaled distances set, along with the speed limit of 60 km/hour. Another constraint is that the van resource has a capacity of one copier.

IV. Data Analysis

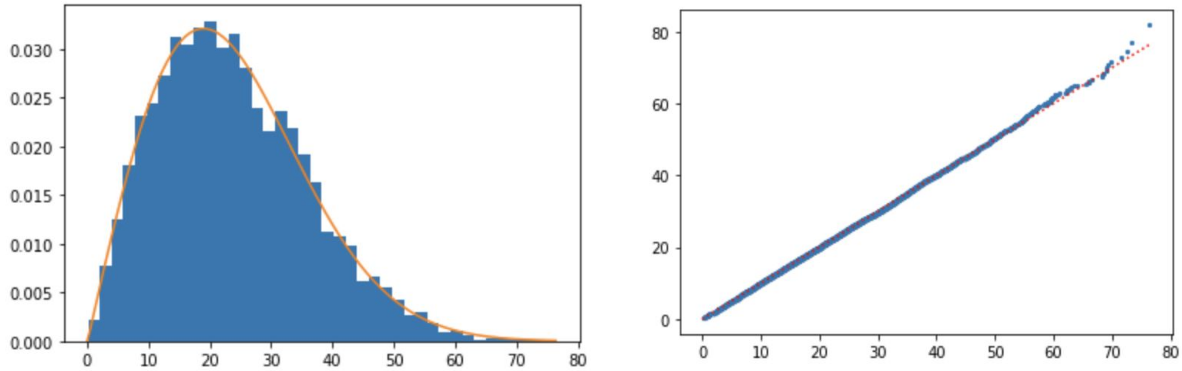
TIDInc provided a dataset that contained a substantial amount of data related to the customer requests over 60 days. This includes request number, day, time of day, request location, initial diagnosis time, whether the request should be fixed offsite or onsite, and the onsite repair time. Our initial task was to understand the data collected, clean the dataset of outliers, and fit input distributions. First, logs of the requests for which the time of day recorded is greater than

24 were removed from the dataset, as it would not be useful to keep these data points when trying to find the inter-arrival rates within one day.

The first analysis found was that the fraction of customer requests that required an off-site repair is normally distributed with a mean of 0.1805 and a standard deviation of 0.3846. A key assumption made was that each data point is independent and identically distributed. This is important to drive our model because 18.05% of the requests are now labeled as ModelEntity1. In other words, 18.05% of requests would require a mechanic's diagnosis followed by a van operator's swap of broken with functional copier in order for the request to leave the system. Following that logic, 81.95% of the requests are labeled as ModelEntity0, which would allow the request to immediately leave the system, after the mechanic has completed both the diagnosis and onsite repair.

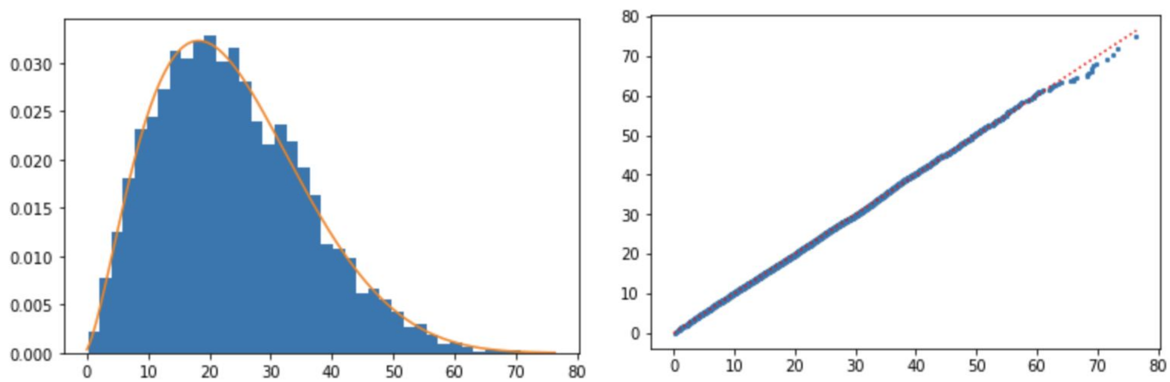
The second major analysis was to fit a distribution to the mechanic's on-site repair times. For this component, a histogram of the onsite repair times was plotted, and it resembled a continuous distribution. Therefore, we proceeded to perform Kolmogorov-Smirnov tests for various continuous distributions such as normal, lognormal, exponential, gamma, rayleigh, and beta distributions. According to the p-value, the two distributions that appear to fit the data the best are the beta distribution and the rayleigh distribution. To visualize the fit of these various distributions, we also compared the fitted probability density functions of these distributions against the histogram of the onsite repair times. This confirmed our initial finding that the beta and rayleigh distributions were the best fit for the data. The Q-Q plots of rayleigh and beta acted as additional confirmation the on-site repair data plausibly were either rayleigh or beta distributed. Simio lacks a random rayleigh distribution, so a Beta distribution was used in place.

Rayleigh: Fitted PDF vs. Histogram (40 bins), Q-Q Plot



p-value: 0.5268019074548904

Beta: Fitted PDF vs. Histogram (40 bins), Q-Q Plot



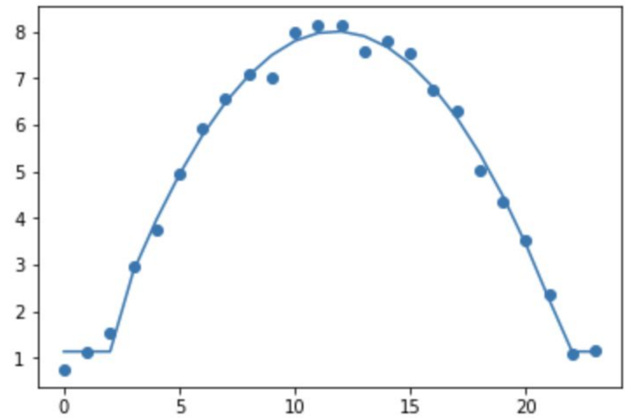
p-value: 0.6979057408649625

The next analysis studied the diagnosis times of the mechanics at each business center. To see whether there was a significant difference in diagnosis times for each business center, we grouped the data by business center and computed the means and standard deviations of diagnosis times. The means and standard deviations of BC 2, 3 and 9 seemed to be fairly different from the rest of the business centers' means & SDs. Business centers 2, 3, and 9 have diagnosis time means of about 22.1 with a SD of about 5.3, whereas all other business centers have means of about 16.1 and SD 2.9. Hence, we decided to separate the initial diagnose times into two groups of business centers: Group 1 includes BC 1, 4, 5, 6, 7, 8, and 10. Group 2 includes BC 2, 3, 9. We created a new column in the data set to contain values of either 1 or 2, a 1 if the business center belongs in Group 1 as we defined, and 2 if the business center belongs in Group 2. The initial diagnosis times of Group 1 and Group 2 were fitted with separate distributions. For both groups, the data points were fitted with a normal distribution, and K-S tests were performed to clarify. The results confirmed that the normal distribution is a good fit for both groups. Therefore, Group 1 was modeled as a normal distribution with a mean of 16.13 and SD 2.89, whereas Group 2 was modeled as a normal distribution with a mean of 22.15 and SD 5.35. Next, the processing time expression was determined. The processing time for a request labeled as onsite is the initial diagnosis times (by Groups 1 and 2) and onsite repair times combined. Refer to Appendix E. for a breakdown of initial diagnosis times by business center.

Our team now needed to estimate the fraction of calls that originate at each business center. Pandas' groupby function allowed us to group the requests data by each business center and take this value as a fraction of the entire number of data points. Our assumption of independent and identically distributed data points further allowed us to compute the standard deviation of the fraction of calls and have confidence intervals for the fractions of calls. Refer to Appendix F. for the fraction of calls that originate at each business center.

Lastly, we found the number of arrivals during each hour of the day over the 60 days of data. Then, we calculated the estimated arrival rate for each hour as the number of arrivals in each hour divided by 60. By plotting the empirical rates, we observed that the rate function is approximately quadratic between 3am and 22pm. We fit a quadratic function to the estimated hourly rates with the function $-0.067i^2 + 1.581i - 1.289$. We assumed the rate is constant for the other hours, which is estimated to be 1.137. We plot the fitted rate function against the empirical rates and saw that it is a good fit. Refer to Appendix B for the rates of requests by hour.

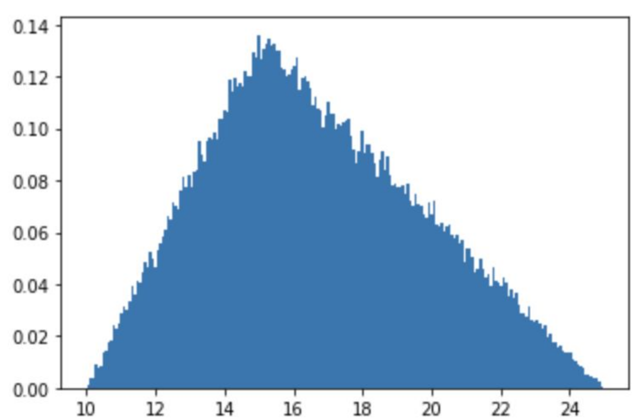
Rate Function Plotted Against Empirical Rates



The rate function is quadratic between 3am and 22pm. Rate is constant(1.137) at other hours.

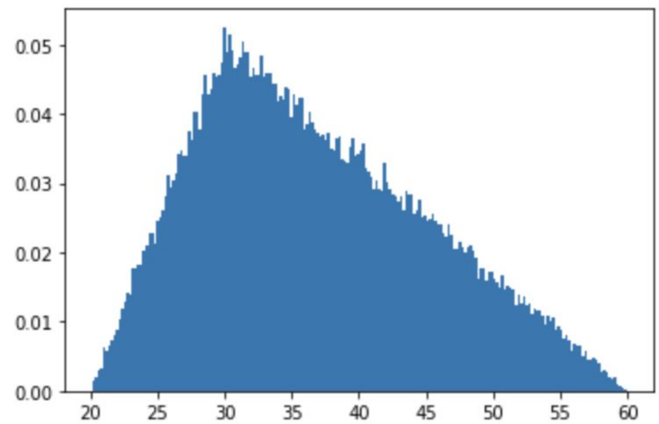
The last component of the dataset to be interpreted was the swapping times of the van operator. From the project description, we concluded that the swap time for dispatch center is distributed as Triangular(min=10,max=25, most likely=15) minutes and the swap time at the customer location is distributed as Triangular(min=20,max=60, most likely=30) minutes.

Copier Swapping Time at Dispatch Center



Triangular distribution with minimum 10, maximum 25, mode 15 min. Drawn 100,000 samples.

Copier Swapping Time at Business Centers



Triangular distribution with minimum 20, maximum 60, mode 30 min. Drawn 100,000 samples.

Therefore we have extracted all the key information from our data to model our repair network.

V. Model Verification

To verify that our model is indeed correct, we used a static M/M/c queueing model. We first calculated the average time that a worker spends on the road by taking the average distance traveled between all nodes and dividing by the speed limit. Taking the average distance of 37.4 km and dividing by the 60km/hr, we obtained an average of 0.6233 hours. The average time to diagnose is (7*16.13 + 3*22.15)/10, which is 17.95 minutes or 0.299 hours. The total service time is 0.9224. The arrival rate is the average of the hourly arrival rates, which is 4.935.

Average	Minimum	Maximum	Half Width			Scenario			
						8M4V			
Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average	Minimum	Maximum	Half Width
Model	Model	deliverytime	UserSpecified	TallyValue	Average	2.9434	2.7392	3.2494	0.0132
		IRT	UserSpecified	TallyValue	Average (Hou...	0.7917	0.6483	0.9398	0.0077
Sink	vanfix	[DestroyedEntities]	FlowTime	TimeInSystem	Average (Hou...	2.9434	2.7392	3.2494	0.0132
		InputBuffer	Throughput	NumberEntered	Total	666.6600	82.0000	741.0000	3.8012
				NumberExited	Total	666.6600	82.0000	741.0000	3.8012
	fix	[DestroyedEntities]	FlowTime	TimeInSystem	Average (Hou...	1.5433	1.3283	1.7796	0.0119
		InputBuffer	Throughput	NumberEntered	Total	3,028.3350	07.0000	185.0000	7.8515
				NumberExited	Total	3,028.3350	07.0000	185.0000	7.8515
Worker	mechanic	[Population]	Capacity	ScheduledUtilization	Percent	65.8713	62.5707	69.9258	0.1990
				UnitsAllocated	Total	3,694.2100	68.0000	349.0000	8.4047
				UnitsScheduled	Average	8.0000	8.0000	8.0000	0.0000
				UnitsUtilized	Average	5.2697	5.0057	5.5941	0.0159

	A	B	C	D	E
1	**M/M/c Queue**				
2					
3					
4	**lambda**	4.935	(arrival rate)		
5	**mu**	0.922	(service rate)		
6	**c**	8.000	(number of servers)		
7					
8					
9	**rho**	0.669	(utilization)		
10	**L**	5.802	(mean number in system)		
11	**w**	1.176	(mean time in system)		
12	**wQ**	0.092	(mean time in queue)		
13	**LQ**	0.452	(mean number in queue)		
14	**P0**	0.004	(probability of an empty system)		

Looking at the static model, we see that the expected utilization is 66.9%, which is close to the 65.8713% that we got in the actual model. However, the average time in system is slightly higher than in the static model. This is expected since we could have underestimated the time it takes for service. Given that the results of both models are similar, the model is verified. Both vans and mechanics are set to return to the dispatch node when idle, which is often the case in practice. Since there are only a small fraction of requests that required the use of a van, we expect to see less vans than mechanics needed in the system, which is indeed true.

From the graphs:

	Actual model	**Static model**
utilization(mechanic)	65.8713%	66.9%
Mean time in system	1.5433	1.176

VI. Model Analysis

In order to determine the optimal number of resources, our team ran an experiment with ten scenarios. Each experiment was replicated 200 times with a duration of 24 hours. The fifth scenario yielded the desired results of performance metrics. Our team recommends TIDInc.'s repair division to invest in eight vans and four mechanics, as this will ensure TIDInc.'s success against its competitors in the Syracuse area, while keepings costs as minimized as possible.

The first performance metric checked was initresponse, and with the optimal combination of resources, we were able to achieve an initial response time for mechanics that performed better than the competitors' average. The mean of the initial response for this renovated repair network of TIDInc. will be at most one hour. We ended up with 0.79 hours, which is well under the ceiling that we had an hour by the company executives. This ensures that the time frame from when a request is sent to when a mechanic arrives at the appropriate business center will be within one hour 95% of the time.

The second key performance metric tested was replacement time for copiers, which was labeled as DoneSwap in our Simio responses. Our team aimed to lower this time to at most three hours, and it was critical to consider both the number of mechanics and vans for this metric. The mean of the completion of swapping time will be at most three hours with 95% confidence. The value of 2.94 hours was under our desired value. Hence, our team is confident in our recommendations to TIDInc's management. We suggest the investment of eight mechanics and four vans. Refer to Appendix G for a detailed visualization including SMORE plots and the ten scenarios that were tested.

Our team decided to perform a sensitivity analysis to confirm our recommendations. After taking the floor and rounding of all interarrival times, we ran the model again to see if a slight change to the inputs will cause a significant difference in the end result.

<u>Floor</u>

Average | Minimum | Maximum | Half Width

						Scenario: 8M4V			
Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average	Minimum	Maximum	Half Width
Model	Model	deliverytime	UserSpecified	TallyValue	Average	2.7426	2.5661	2.9767	0.0107
		IRT	UserSpecified	TallyValue	Average (Hou...	0.6654	0.5781	0.8307	0.0061
Sink	vanfix	[DestroyedEntities]	FlowTime	TimeInSystem	Average (Hou...	2.7426	2.5661	2.9767	0.0107
		InputBuffer	Throughput	NumberEntered	Total	604.5200	42.0000	566.0000	3.3235
				NumberExited	Total	604.5200	42.0000	566.0000	3.3235
	fix	[DestroyedEntities]	FlowTime	TimeInSystem	Average (Hou...	1.3461	1.2181	1.5924	0.0093
		InputBuffer	Throughput	NumberEntered	Total	2,742.2300	95.0000	357.0000	7.3554
				NumberExited	Total	2,742.2300	95.0000	357.0000	7.3554
Worker	mechanic	[Population]	Capacity	ScheduledUtilization	Percent	58.8989	55.0454	62.3406	0.1981
				UnitsAllocated	Total	3,346.0550	69.0000	490.0000	8.6269
				UnitsScheduled	Average	8.0000	8.0000	8.0000	0.0000
				UnitsUtilized	Average	4.7119	4.4036	4.9872	0.0158

<u>Rounded</u>

Object Type	Object Name	Data Source	Category	Data Item	Statistic	8M4V Average	Minimum	Maximum	Half Width
Model	Model	deliverytime	UserSpecified	TallyValue	Average	2.9251	2.6981	3.1785	0.0128
		IRT	UserSpecified	TallyValue	Average (Hou...	0.7768	0.6386	0.9589	0.0077
Sink	fix	[DestroyedEntities]	FlowTime	TimeInSystem	Average (Hou...	1.5211	1.3189	1.8096	0.0119
		InputBuffer	Throughput	NumberEntered	Total	2,961.9650	81.0000	141.0000	8.1058
				NumberExited	Total	2,961.9650	81.0000	141.0000	8.1058
	vanfix	[DestroyedEntities]	FlowTime	TimeInSystem	Average (Hou...	2.9251	2.6981	3.1785	0.0128
		InputBuffer	Throughput	NumberEntered	Total	656.6600	91.0000	713.0000	3.3359
				NumberExited	Total	656.6600	91.0000	713.0000	3.3359
Worker	mechanic	[Population]	Capacity	ScheduledUtilization	Percent	64.3902	59.6304	68.7858	0.2075
				UnitsAllocated	Total	3,617.0300	02.0000	301.0000	8.7573
				UnitsScheduled	Average	8.0000	8.0000	8.0000	0.0000
				UnitsUtilized	Average	5.1512	4.7704	5.5029	0.0166

From the results, we can see that the altered inputs have a minor effect on the overall result. In both cases having 8 mechanics and 4 vans met the required initial response and delivery time.

VII. Conclusion

In conclusion, TIDInc. is urged to spend a total of $1.52 million with the exact combination of eight mechanics and four vans to stay in business by keeping its current customer base. Without a strong repair network, TIDInc will fail to provide service to customers in a timely manner and fall further behind its competition. This number of resources will ensure that the average initial response times and delivery times for replaced copiers will remain lower than TIDInc's competitors' with 95% confidence.

The optimal number of mechanics is eight, to keep the initial response time below the desired threshold. With eight mechanics, specifically four vans are necessary to keep the network replacing copiers with a total time of at most three hours. We tried various experiments and various ways to alter the model to give the best recommendation to TIDInc., however, with our current results with eight mechanics and four vans we achieved the desired initial response time and the lowest cost, satisfying both demands of the company.

Our recommendation for this project would be to use the above number of mechanics and vans and from a business standpoint to continue to develop deeper and more loyal relationships with customers. For the nontechnical senior management, we would ask that besides focusing on the number of mechanics and vans, they should focus more on relationship development with customers, that way even if initial response or delivery times are a bit higher, the relationship would prompt the customer to use TIDInc services.

This would ultimately help improve the current delivery processes as well as increase revenue as more customers would seek to use TIDInc's repair services. We are excited to see what the company could potentially achieve with these new recommendations.

VIII. Appendix

Appendix A: Model Description

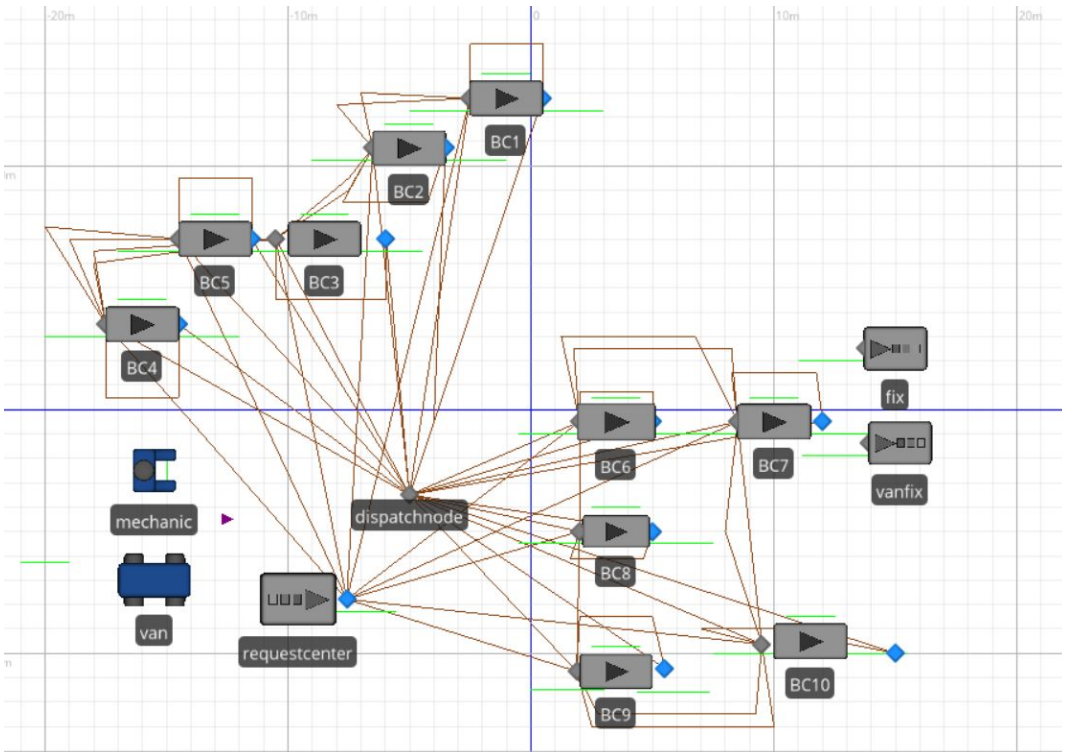


Figure 1: The above displays our simulation network with requestcenter, dispatchnode, the mechanic, van, business centers, vanfix, and fix. Arrows were removed for clarity of the model

Model Entities:

- Requests (two ModelEntity.Picture)

Source Object: requestcenter

- Entity Type: requests
- Arrival Mode: Time Varying Arrival Rate
- Rate Table: request_time (**Appendix B**)
- Rate Scale Factor: 1.0
- Entities Per Arrival: 1
- State Assignments: Before Exiting
  - State Variable: Business
  - Value: Random.Discrete(1,.039509,10,.181907,2,.2639955,3,.371911,4,.507329,5,.6257155,6,.6807205,7,.8045515,8,.862488,9,1)

Sink Objects:

- fix: where requests that only require on-site repair go to be deleted from the system

- vanfix: where requests that require off-site repair go to be deleted from the system

Servers:

- BC 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
- Capacity Type: Fixed
- Initial Capacity: Infinity
- Processing Time:
  - Units: Minutes
  - For BC 1, 4, 5, 6, 7, 8, 10: Math.Abs(Math.If(ModelEntity.Picture == 0, Random.Normal(16.13,2.89) + Random.Beta(2.618,7.462),Random.Normal(16.13,2.89)))
  - For BC 2, 3, 9: Math.Abs(Math.If(ModelEntity.Picture == 0, Random.Normal(22.15,5.35) + Random.Beta(2.618,7.462),Random.Normal(22.15,5.35))
- Secondary Resources: Resource for Processing
  - Object Type: Specific
  - Object Name: mechanic (worker)
  - Selection Goal: Smallest Distance
  - Request Move: To Node
  - Destination Node: Input@BC#
- Add-On Process Triggers:
  - Before Processing (**Appendix B**)
  - After Processing (**Appendix C)**
    - BC#_EvaluatingSeizeRequest

<u>Nodes:</u>

- Dispatchnode:
  - Initial Traveler Capacity: Infinity
- Input Nodes at BCs
  - Initial Traveler Capacity: Infinity
  - State Assignments: On Entering: Basic Logic:
    - Assign If: Entity Entering
    - State Variable Name: ModelEntity.Picture
    - New Value: Random.Discrete(0, 0.8195, 1, 1)
    - With a probability 0.8195, the request does not require an off-site visit from the van operator.

<u>Connectors:</u>

- Between Nodes:
  - Output@request center(Transfer Node)

    - Input @ BC#
- Routing Logic:
    - Selection Weight: Business == #
- Using the State Assignments created at the Source, where Business = = the probability of a request coming from that Business Center, a mechanic is sent to the input node of a Business Center if the call is indeed from that BC.

Paths: 3 major types
- Between Nodes: dispatchnode, Input @ BC
    - Speed Limit: 60

Dispatch Node, Input @ Business Centers	**Logical Length (in km)**
BC 1	45
BC 2	45
BC 3	35
BC 4	50
BC 5	55
BC 6	25
BC 7	35
BC 8	30
BC 9	35
BC 10	45

- Between Nodes: Output @ BC, dispatchnode
    - Speed Limit: 60
        - Units: Kilometers per Hour
    - Routing Logic: Selection Weight:
        - Selection Weight: ModelEntity.Picture = = 1
        - Van must go back to dispatch center once completed swapping at the BC, whereas a mechanic does not. ModelEntity.Picture = = 1 indicates the use of a van for off-site repair.

Dispatch Node, Output @ Business Centers	Logical Length (in km)
BC 1	45
BC 2	45
BC 3	35
BC 4	50
BC 5	55
BC 6	25
BC 7	35
BC 8	30
BC 9	35
BC 10	45

Resources:

- mechanic (Worker)
    - Capacity Type: Fixed
    - Routing Logic:
        - Initial Node (Home): dispatchnode
        - Mechanics are dispatched from the dispatchnode, which symbolizes the Dispatch Center of the TIDInc. Repair Network
    - Population:
        - Initial Number in System: NumMech
        - Set a referenced property to go back and run experiments and analyze optimal number of mechanics needed for the repair network
- van (Vehicle)
    - Initial Ride Capacity: 1
    - Load Time: Random.Triangular(10,15,25)
        - Units: Minutes
    - Travel Logic:
        - Initial Desired Speed: 60 Kilometers per Hour
    - Routing Logic:
        - Initial Node (Home): dispatchnode
        - Vans are dispatched from the dispatchnode, and sent back to the dispatchnode always before processing another off-site repair request.

    - Population:
        - Initial Number in System: NumVan
        - Set a referenced property to go back and run experiments and analyze optimal number of vans needed for the repair network

<u>Experiments:</u>

- Warmup Period: 100 hours
- Ending Type: 5 weeks
- Confidence Interval: 95%
- Replications: 200

- Responses:
    - SumCosts: (140000*mechanic.Population.Capacity) + (100000*van.Population.Capacity)
        - Units: USD
    - DoneSwap: deliverytime.Average
        - Units: Hours
    - Initresponse: IRT.Average
        - Units: Hours

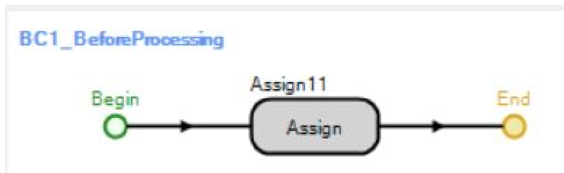
Appendix B: Rate of arrivals of the requests (calls): request_time

Hour	**Rate (Calls per Hour)**
0	1.136667
1	1.136667
2	1.136667
3	2.848897
4	3.959323
5	4.935269
6	5.776733
7	6.483717
8	7.056219
9	7.494241
10	7.797783
11	7.966843
12	8.001423
13	7.901521
14	7.667139
15	7.298277
16	6.794933
17	6.157108
18	5.384803
19	4.478017
20	3.436750
21	2.261003
22	1.136667
23	1.136667

Appendix C: Add-On Process Triggers (At Server): Before Processing

Example:

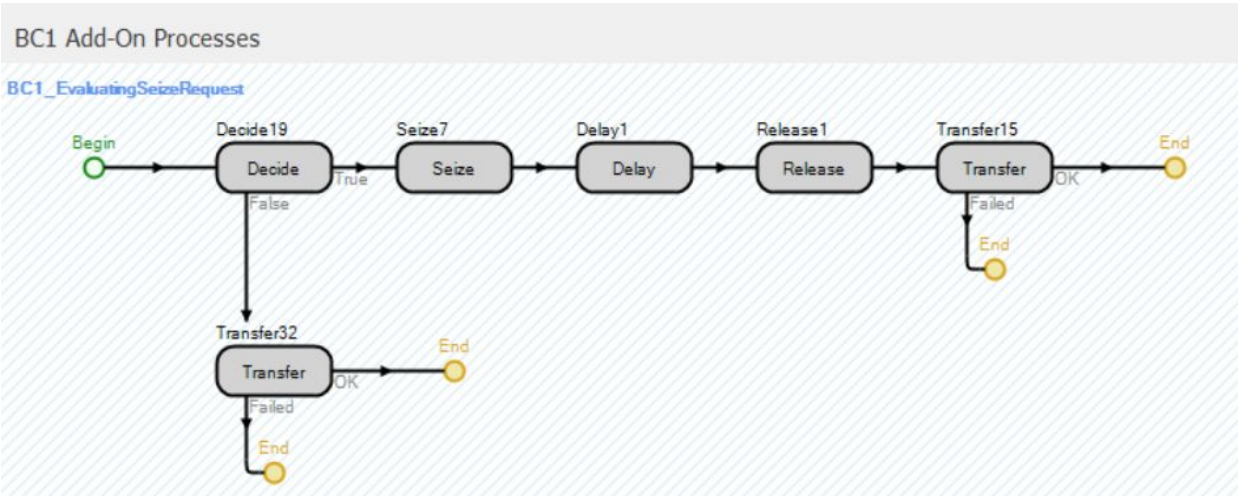
- Category: BC 1 Add-On Processes
    - Name: BC1_BeforeProcessing
- Basic Logic:
    - State Variable Name: ModelEntity.IRT
    - New Value: TimeNow - ModelEntity.TimeCreated



Appendix D: Add-On Process Triggers (At Server): After Processing

Example:

- Category: BC1 Add-On Processes
  - Name: BC1_EvaluatingSeizeRequest
- Decide: Deciding whether a van is needed (1) or only on-site is required (0)
  - Decide Type: Condition Based
  - Condition or Probability: ModelEntity.Picture == 1
    - This acknowledges the requirement of an off-site repair, implying the need of a van resource (vehicle type).
- Seize: Seizing the resource (van, vehicle type)
  - Resource Seizes: 1
    - Object Type: Specific
    - Object Name: van
    - Selection Goal: Preferred Order
    - Request Move : To Node
    - Destination Node: Input @ BC 1
- Delay: Processing the swapping of copiers and installation
  - Delay Time: Random.Triangular(20,30,60)
  - Units: Minutes
- Release: Release the resource (van) after completion of process
  - Resource Releases: 1
    - Object Type: Specific
    - Object Name: van
- Transfer (Transfer15):
  - From: Any
  - To: Node
  - Node Name: Input@vanfix
  - This marks the completion of the swapping of copiers at the business center, and the work of the van operator is finished. The request leaves the system through the sink, vanfix.
- Transfer (Transfer32):
  - From: Any
  - To: Node
  - Node Name: Input@fix
  - This marks the completion of the on-site repair at the business center, and the work of the mechanic is finished. The request leaves the system through the sink, fix. This option of Transfer is taken when Decide evaluates to 0, or ModelEntity.Picture == 0, which indicates that an off-site repair is not required.

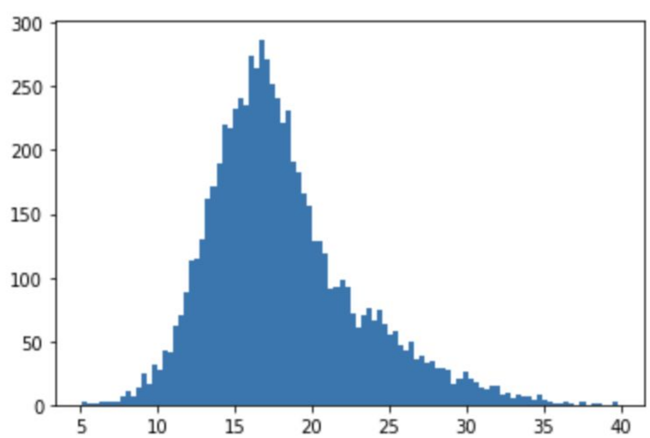


BC1 Add-On Processes
BC1_EvaluatingSeizeRequest
Begin
Decide19
Decide
True
False
Seize7
Seize
Delay1
Delay
Release1
Release
Transfer15
Transfer
OK
Failed
End
End
Transfer32
Transfer
OK
Failed
End
End

Appendix E: Initial Diagnosis Times - Data Analysis

Initial Diagnosis Times		
Business Center(BC)	**Mean (Min)**	**Standard Deviation (Min)**
1	15.974684	2.954169
2	22.174312	5.248368
3	22.009613	5.405268
4	16.175101	2.851679
5	16.200575	2.882792
6	16.151506	2.847626
7	16.011773	2.923965
8	16.269802	2.875527
9	22.236205	5.358455
10	16.109307	2.919997

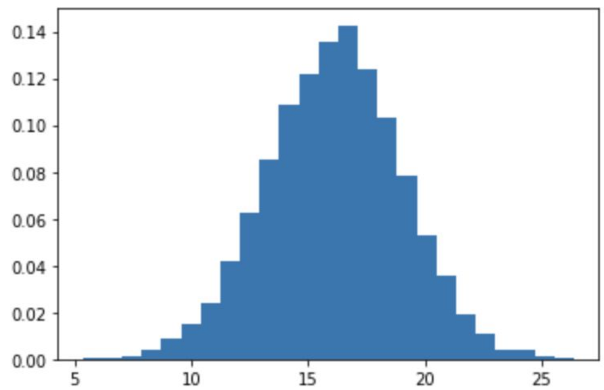
Initial Diagnosis Times



Skewed distribution →Separated into two groups

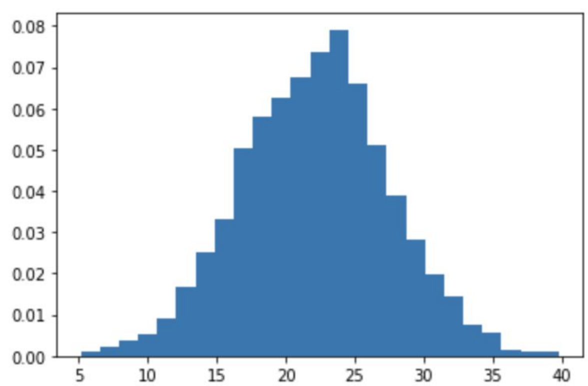
Group 1: BC 1, 4, 5, 6, 7, 8, 10

Initial Diagnosis Times: Group 1



Group 2: BC 2, 3, 9

Initial Diagnosis Times: Group 2



Appendix F: Origin of Requests

Business Center	Fraction of Calls
1	0.039509
2	0.082089
3	0.107916
4	0.135418

5	0.118386
6	0.055005
7	0.123831
8	0.057937
9	0.137512
10	0.142398

Appendix G: SMORE Plots

Scenario		Replications		Controls		Responses		
Name	Status	Required	Completed	NumMech	NumVan	SumCosts (...	DoneSwap	initresponse
Test	Comple...	200	200 of 200	9	5	1.76E+06	2.60079	0.582765
Scenario2	Comple...	200	200 of 200	9	4	1.66E+06	2.6257	0.579384
Scenario3	Comple...	200	200 of 200	9	3	1.56E+06	2.75557	0.585449
Scenario4	Comple...	200	200 of 200	8	5	1.62E+06	2.92438	0.788091
Scenario5	Comple...	200	200 of 200	8	4	1.52E+06	2.94337	0.791725
Scenario6	Comple...	200	200 of 200	8	3	1.42E+06	3.05249	0.786992
Scenario7	Comple...	200	200 of 200	7	5	1.48E+06	3.55863	1.19575
Scenario8	Comple...	200	200 of 200	7	4	1.38E+06	3.55689	1.19121
Scenario9	Comple...	200	200 of 200	7	3	1.28E+06	3.63786	1.19109

Figure 1: The above represents the different experiments we tested in simio. We ran a total of 10 experiments with 200 runs each. We felt that this was a good number of replications because our values started to converge at the same value with replications greater than 200. We see that after 8 mechanics and 3 vans our initial reponse time goes above 1 hr. We tried multiple combinations of mechanics and vans to find the limit to be 8 mechanics and 3 vans.

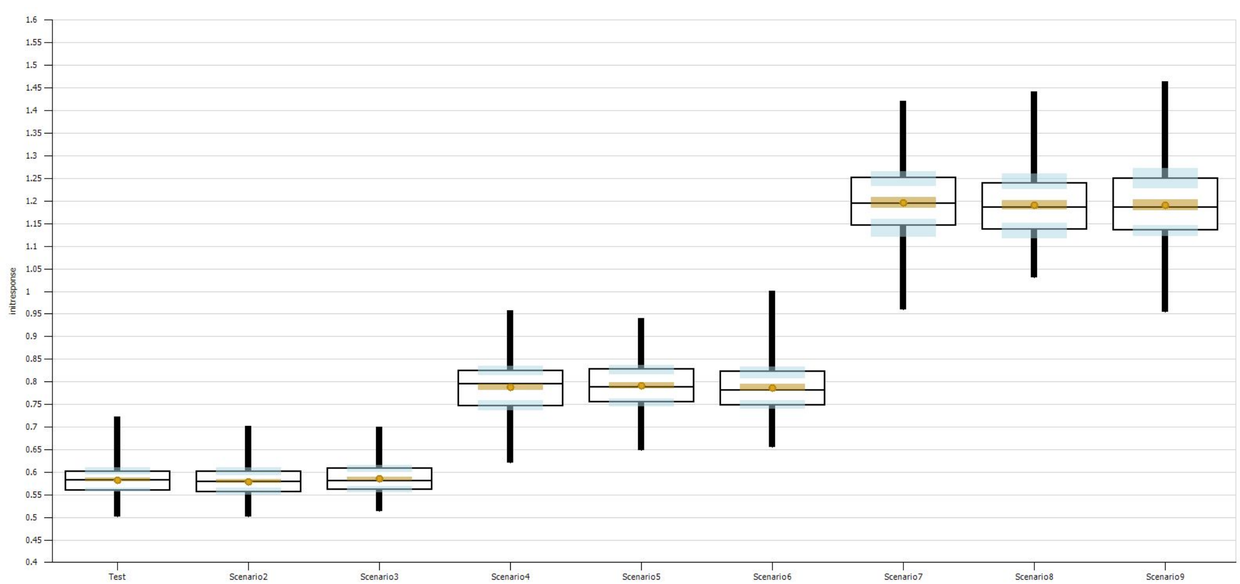


Figure 2: This is a SMORE plot of the initial response time with respect to the different scenarios conducted. We see that we can group our results into 3 groups. Test, Scenario 2, and Scenario 3 seems to linger around .6 hrs as their response time, while Scenario 4 - 6 seem to be around .8 hrs. The last 3 scenarios were our tests to see what values would surpass the target response time of at most 1 hour. Scenario 7, 8, 9 were our verifications that our optimal answer was correct.

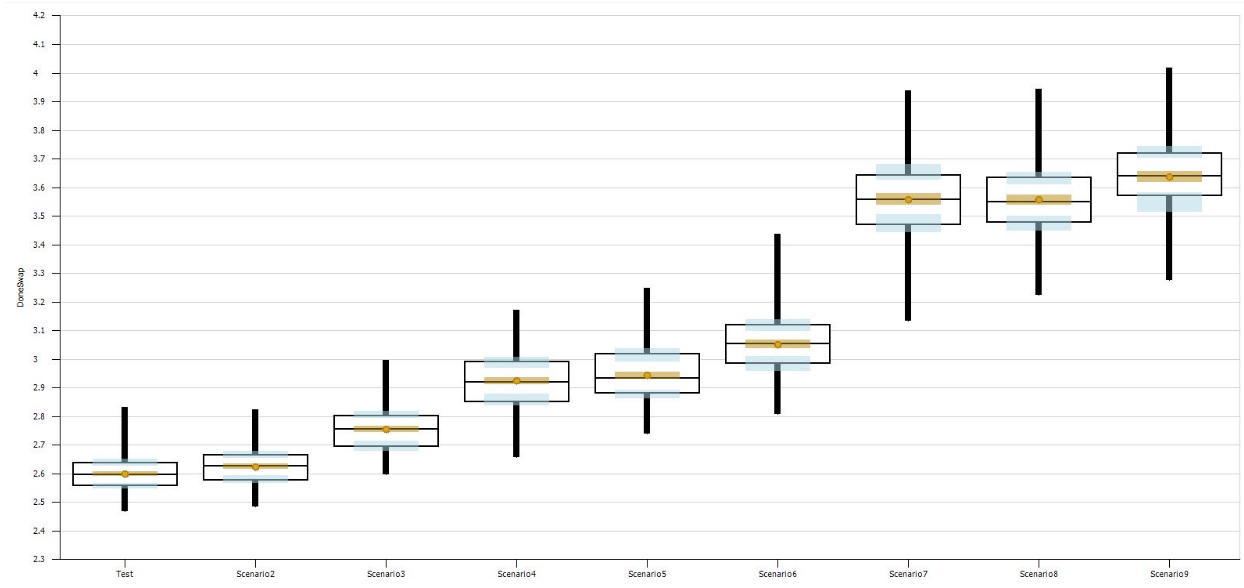


Figure 3: From our SMORE plot of the DoneSwap metric we see that again there seems to be three groups of times. One around 3.5 hrs, another around 3 hrs, and lastly around 2.6 hrs.

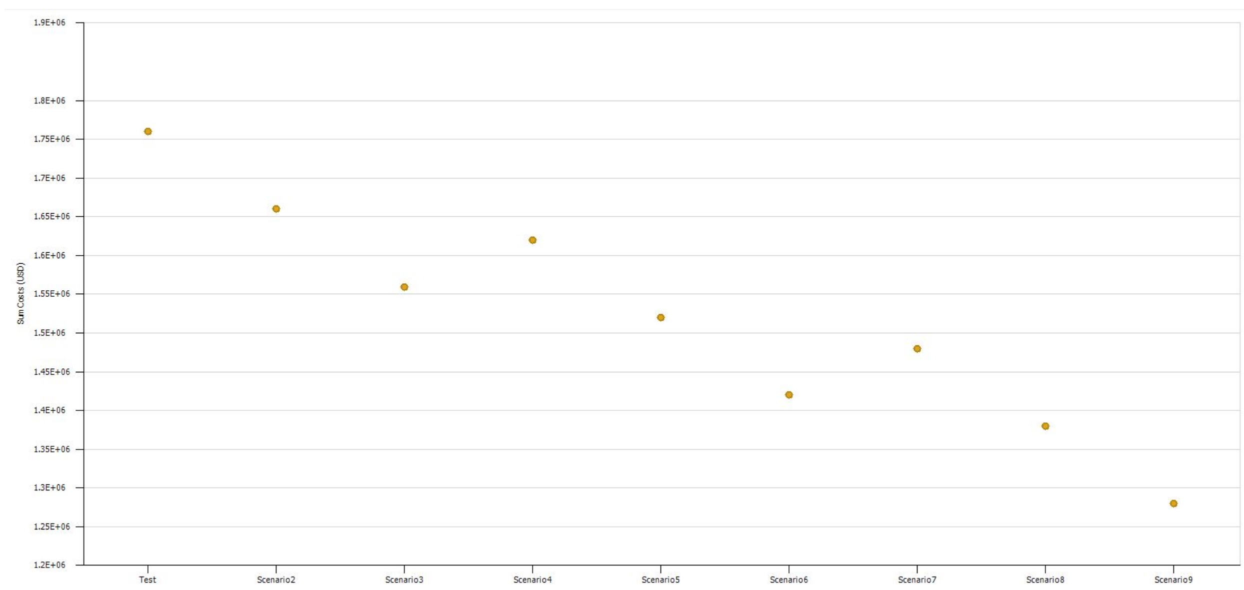


Figure 4: This plot is important because the reason the company wants to lower initial response time is because they want to serve customers faster, get more loyalty, and earn more money. This plot shows that scenario 6 has the initial response time below our goal of at most an hour and shows lower costs. Even though scenarios 1-5 have relatively lower initial response times, the cost is higher. Therefore, scenario 6 is most favorable in terms of costs, delivery time, and initial response time.