Rochester Institute of Technology

Boston Duck Boat Tour Simulation

Design of Experiments

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Background

The Boston Duck Boat Tours are a unique, fun, and historical tour around Boston by land and water. This tour is great for friends new to the city and for families that want a memorable experience. There are three different locations to start the tour, the Prudential Center, the Museum of Science, and the New England Aquarium. Costumers are to purchase their ticket online and then wait for their tour.

Problem Description

Given the popularity of the tour, customers are expected to have a long waiting time when deciding to purchase their ticket. A longer wait for the service takes away from the intended positive experience. An expected long wait prevents the opportunity of this experience for customers who don't have enough time. Several factors impact the average waiting time for a costumer and six factors will be investigated to prevent the issue of a long wait.

Objective

This experiment will model a simulation of the process from the costumers' perspective, from the ticket purchase to the finish of the tour. The goal is to minimize the costumer waiting time by determining the level for each significant factor and two-way interaction which decreases waiting time.

Response Variable

The response variable for this study is the average waiting time [minutes] between the time of purchase and the time of service for all costumers in an 8.5 hour day, 8am – 5:30pm. This response variable provides accurate information about this stochastic process because it is a queuing system. Costumers arrive based on the online time stamp of their purchased ticket. Then they wait for their service in a First-In-First-Out online queue of purchased tickets. They receive the service of the tour, and exit the system.

The measurement system of the response is the software, Simio 7. Simio 7 is easy to control, and will be an accurate homogeneous measurement system of the final model created. The simulation will record the waiting time for hundreds of customers under each scenario and average them together for the response value of each scenario for every replication. Simio 7 will only record data during the steady state of the process when the system is filled with costumers.

Design Factors

There are six factors in this experiment which are outlined below in Table 1. There are five continuous factors and one categorical factor, Distribution Process. The Distribution Process factor represents the random distribution for the length of the duck boat tour. Both Distribution Process levels have a fixed standard deviation of 5 [minutes]. Therefore this is not included in this experiment as a design factor, but as a fixed factor. The Down Time factor represents how long a scheduled boat is temporarily unavailable due to technical or mechanical issues. This results in an extended wait for the corresponding customers who purchased a ticket for that boat. Down Time will occur once a day. The Interarrival Rate factor represents how often a ticket is purchased by a group of 3 or 4 people. There is a 50/50 chance that it is a group of 3 people or 4 people for any arrival.

The Number of Boats was found online to be 20 boats, and the low level was chosen to be half of that to represent the system when boats are unavailable. The levels for the Distribution Process were based on the assumption of normality. The Mean Process Time was found online to be 80 minutes and 90 minutes was chosen as the high level to account for natural variability of the length of a tour. Down Time levels were set at relatively small values to represent the daily maintenance checks of the duck boats. Boat Capacity was found online to be 36 people and the low level was set at 20 to represent slow days when boats aren’t filled up completely. The Interarrival Rate levels were set during the creation of the pilot model to determine which values resulted in no more than 600 customers on a daily basis.

Design Factors	**Range of Levels**		**Units**
	Low Level	*High Level*	
Number of Boats	10	20	*[boats]*
Distribution Process	Normal	Lognormal	*[type]*
Mean Process Time	80	90	*[minutes]*
Down Time	15	45	*[minutes]*
Boat Capacity	20	36	*[people]*
Interarrival Rate	3	8	*[minutes/3 or 4 people]*

Table 1: Choice of Factors, Levels/Ranges, and Units

Experiment Design

The design of this experiment is a 2^K Factorial Design with 6 factors at a 0.05 Level of Significance. The model for this experiment is a Second Order Empirical Model for minimizing the response variable. The design is chosen to be factorial because of the several factors that go into average waiting time. The factorial design is 2^K to allow for clear two-way interactions between all factors. The model was chosen to be of the second order because that is typically used for optimization objectives. The empirical model is as follows:

Average Waiting Time = β_0 + β_1*Number of Boats + β_2*Distribution Process +

β_3*Mean Process Time + β_4*Down Time + β_5*Boat Capacity + β_6*Interarrival Rate +

β_1 β_2*Number of Boats*Distribution Process + β_1 β_3*Number of Boats*Mean Process Time +

β_1 β_4*Number of Boats*Down Time + β_1 β_5*Number of Boats*Boat Capacity +

β_1 β_6*Number of Boats*Interarrival Rate + β_2 β_3*Distribution Process*Mean Process Time +

β_2 β_4*Distribution Process*Down Time + β_2 β_5*Distribution Process*Boat Capacity +

β_2 β_6*Distribution Process*Interarrival Rate + β_3 β_4*Mean Process Time*Down Time +

β_3 β_5*Mean Process Time*Boat Capacity + β_3 β_6*Mean Process Time*Interarrival Rate +

β_4 β_5*Down Time*Boat Capacity + β_4 β_6*Down Time*Interarrival Rate +

β_5 β_6*Boat Capacity*Interarrival Rate

Design Table

Table 2 below represents the first 32 scenarios, in standard order without replication, of a total 64 scenarios which make up one run for this experiment.

Scenario	Number of Boats	Distribution Process	Mean Process Time	Down Time	Boat Capacity	Interarrival Rate
1	10	Normal	80	15	20	3
2	20	Normal	80	15	20	3
3	10	Lognormal	80	15	20	3
4	20	Lognormal	80	15	20	3
5	10	Normal	90	15	20	3
6	20	Normal	90	15	20	3
7	10	Lognormal	90	15	20	3
8	20	Lognormal	90	15	20	3
9	10	Normal	80	45	20	3
10	20	Normal	80	45	20	3
11	10	Lognormal	80	45	20	3
12	20	Lognormal	80	45	20	3
13	10	Normal	90	45	20	3
14	20	Normal	90	45	20	3
15	10	Lognormal	90	45	20	3
16	20	Lognormal	90	45	20	3
17	10	Normal	80	15	36	3
18	20	Normal	80	15	36	3
19	10	Lognormal	80	15	36	3
20	20	Lognormal	80	15	36	3
21	10	Normal	90	15	36	3
22	20	Normal	90	15	36	3
23	10	Lognormal	90	15	36	3
24	20	Lognormal	90	15	36	3
25	10	Normal	80	45	36	3
26	20	Normal	80	45	36	3
27	10	Lognormal	80	45	36	3
28	20	Lognormal	80	45	36	3
29	10	Normal	90	45	36	3
30	20	Normal	90	45	36	3
31	10	Lognormal	90	45	36	3
32	20	Lognormal	90	45	36	3
…64	…20	…Lognormal	…90	…45	…36	…8

Table 2: 2^6 Standard Order Factorial Design

Blocking

Blocking is not included in this experiment due to the homogenous nature of a simulation model. The experiment won't take any longer by blocking because it isn't present. The time going into the experiment will primary be spent on the creation of the final model in Simio 7. Running the entire experiment will depend on the number of replications, anywhere from 1 – 10 minutes.

Replication

Figure 1 below shows the results for the required amount of replications needed for each factor. The power level is chosen to be 0.8, which is denoted by the black dot at the (0, 0.8) coordinate. The standard deviation and maximum effect for each factor was calculated with the raw data from a pilot run of 10 replications in Simio 7. The replications necessary to meet a power level of 0.8 varies from 2 – 2965820 replications amongst the factors. This shows that the levels chosen for some factors may be resulting in a small effect size.

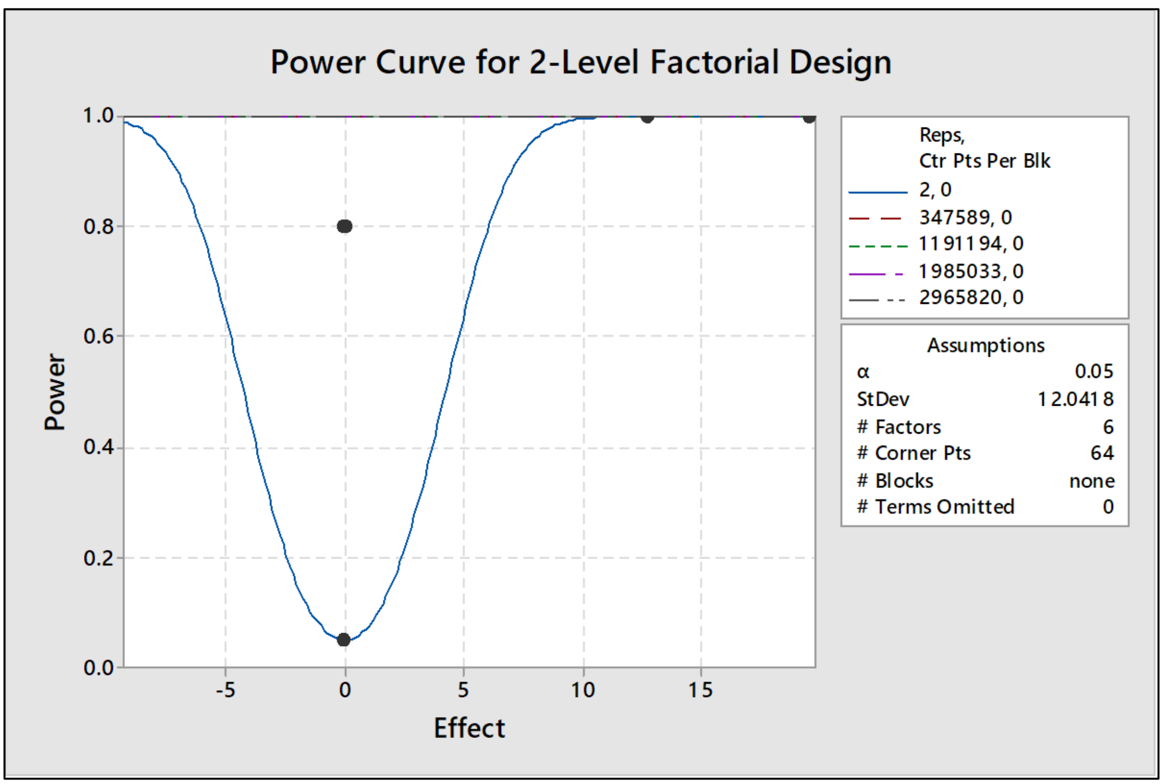

Figure 1: 2^6 Factorial Power Curve

Table 3 below shows which factors have a significant effect between their levels on average waiting time. The larger effects have a darker shade of color. The wide range of replications required for the current design was dealt with by assigning a proportional weight to each factor based on their effect value. The required replication value was calculated by summing the products of replications and corresponding effect weights. This resulted in a weighted average of 809 replications based on the pilot simulation model.

Factor	Center Points	Effect	Reps	Total Runs	Target Power	Actual Power	Effect Weight	Reps 809
Number of Boats	0	0.0077	1191194	76236416	0.8	0.80	0.0002	
Distribution Process	0	0.0060	1985033	127042112	0.8	0.80	0.0002	
Mean Process Time	0	0.0000	2965820	189812480	0.8	0.05	0.0000	
Down Time	0	0.0143	347589	22245696	0.8	0.80	0.0004	
Boat Capacity	0	12.7526	2	128	0.8	1.00	0.3951	
Interarrival Rate	0	19.4988	2	128	0.8	1.00	0.6041	

Table 3: Power Curve Summary Table

Assumptions

1. There will be 3 parallel processes to represent each starting location.
2. Resources are divided equally amongst the locations.
3. Resources are not allowed to be shared between locations.
4. Costumers purchase a ticket on the same day they receive service.
5. Costumers purchase a ticket for the next available tour.
6. Costumers are not allowed to switch starting locations.
7. Normality is assumed for the length of the tour.
8. No more than 600 customers for each location can buy a ticket, based on boat capacity and available online time slots found online.

Works Cited

"Our 2015 Season Has Begun!" *Boston Duck Tours Splash Page*. Web. 21 Mar. 2015. <http://www.bostonducktours.com/>.

"Ride The Ducks of Seattle | It's a Party on Wheels and in the Water!" *Ride The Ducks of Seattle*. Web. 21 Mar. 2015. <http://www.rideducksofseattle.com/>.

Appendix

Figure 2 below shows the number of customers in the system during the run of the pilot model. The black dotted line indicates at what time the system has "warmed-up" and entered steady state. Therefore the first 4 hours of the experiment, 8am – 11am, will not be used in the calculation of the average wait time for each scenario and replication.

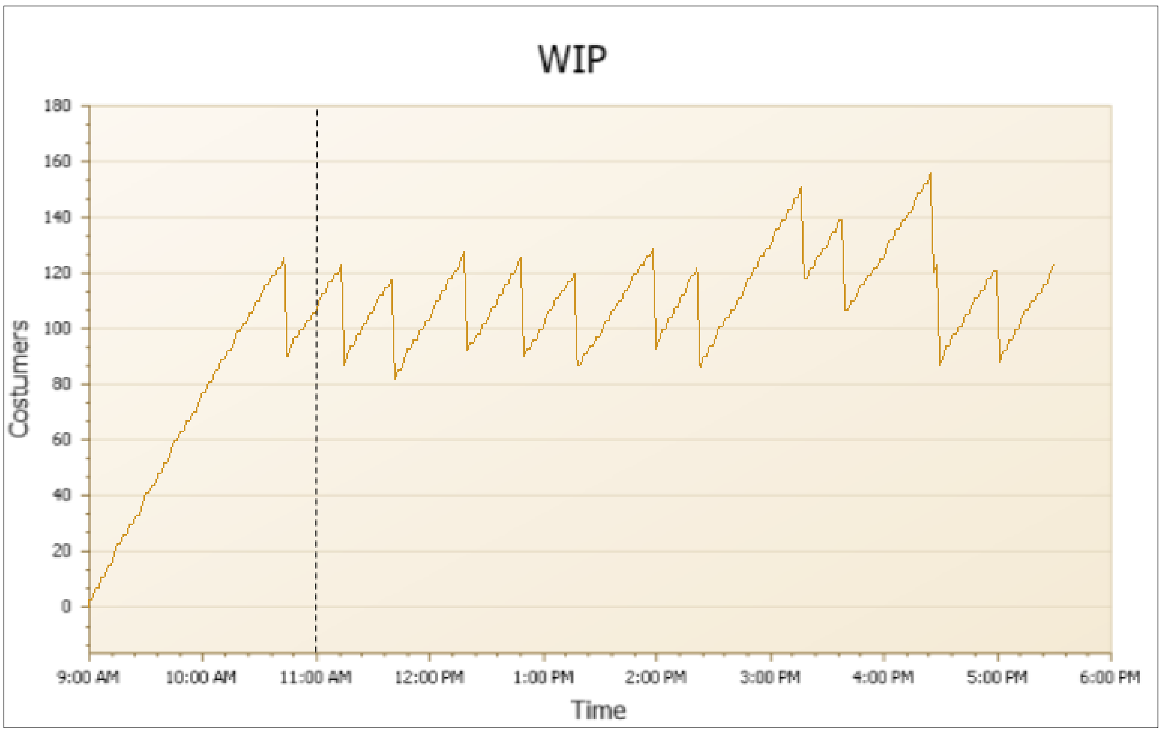

Figure 2: Daily Work in Process