AMS 553 Project - Simulate Disneyland Wait Times

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December 9, 2022

1 Motivation

If you have made a trip to Disney World, you will learn how important it is to plan ahead and check out the crowd levels. It is not surprising that many visitors spend more than two hours waiting for a ride. You may have the experience that you stayed on a queue for several hours waiting for your turn while the system said that it would be only a 45 minutes wait. Longer than expected waiting times can lead to a very bad customer experience. Katz et. al. reported that if customers are aware of their waiting duration, i.e., customers having correct information on the waiting time, they will perceive the waiting to be shorter than actual [1].

Thus, in the project, we are aiming to develop a model to predict the waiting time of attractions in Disney World over time. This project utilizes the queuing theory to model waiting times. Based upon the simulated results, visitors can plan ahead before their trips and obtain correct prediction of when their turns will come, thus significantly improving customer satisfaction.

2 Methodology

In Disney World Orlando, there are 41 rides at Magic Kingdom, 42 at Epcot, and 17 at Disney's Hollywood Studio and 46 at Animal Kingdom. Simulating the whole amusement park is out the scope of this project. In this report, we take one of the most famous attractions in Disney Magic Kingdom - Seven Dwarfs Mine Train as an example to build a model on waiting times over the time of a day. This model can be extended to simulate multiple attractions with slight modification.

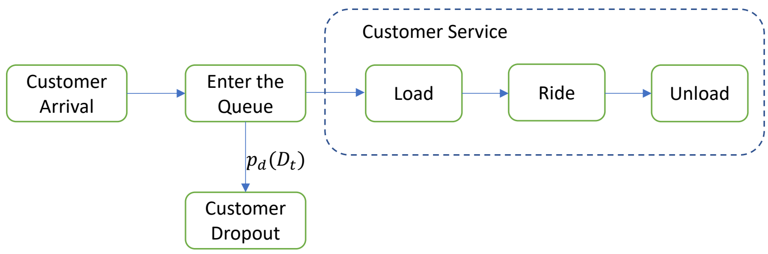

Figure 1: A flow diagram for the queuing model.

Figure 1 illustrates the main components of the model:

1. **Customer Arrival**: customer arrival is simulated as a nonhomogeneous Poisson process with time-dependent rate parameter $\lambda(t)$.
2. **Customer Dropout**: customer dropout follows Bernoulli distribution with dropout rate depending on current queue length or wait time.

3. **Service**: the whole service contains loading, riding and unloading. The riding time is a constant while loading and unloading are assumed to follow uniform distributions.

2.1 Customer Arrival

We simulate customer arrival as a Poisson process where the time interval between two successive arrivals follows an exponential distribution. The arrival rates of customers are time-dependent. According to *Dealing with Magic Kingdom Crowds*[2], The first two to three hours of every day are the time of the lowest crowds of the day. We assume that the arrival rate is monotonically increasing since the open time at 8 a.m. until the peak time around 11 a.m. and it drops dramatically after 3pm. We refer to Cohen et al. [3] to simulate the arrival rate as a polynomial function of time of the day:

$$\lambda(t) = -1.8t^4 + 40.5t^3 - 390t^2 + 1575t + 890 \qquad t \in [0, 10]$$

where $t = 0$ is standing for the open time at 8 a.m..

2.1.1 Simulate the Nonhomogeneous Poisson Process

Generating nonhomogeneous Poisson process is much less intuitive as comparing to homogeneous Poisson process. We implemented the thinning method proposed by Lewis et al. in 1979 which is a "process analogue" of acceptance-rejection[6]. First, find a constant rate $\lambda^* \geq \lambda(t)$, next generate points from the homogeneous Poisson process with λ^*, and then reject an appropriate fraction of the generated events so that the desired rate $\lambda(t)$ is achieved. The algorithm contains following steps:

1. Generate points from homogeneous Poisson process with rate function λ^*.
2. Denote the generated points by $X_1^*, X_2^*, \cdots, X_n^*$. For $i = 1 \cdots n$, repeat steps 3:
3. Generate $u_i \sim U(0,1)$, if $u_i \leq \frac{\lambda(X_i^*)}{\lambda^*}$, then accept and deliver X_i^*.

Note homogeneous Poisson process is simulated by utilizing the property that the time interval between two successive arrivals follows an exponential distribution. Poisson process are obtained by cumulatively summing all of time intervals. Figure 2 presents the arrival rates and the estimated number of arrivals across a whole day. The estimated daily attendance is estimated to be 22,000 which is a reasonable estimation given the reported daily averaged attendance of Magical Kingdom in 2022 is 57,000 visitors per day. We note that the actual customer arrivals is highly dependent on date. The arrival rate function should be updated accordingly based on the actual customer flow.

2.2 Customer Dropout

Reneging occurs a lot when a visitor has been waiting for a long time in the line, and finally decides to leave the queue before being served. We assume customer dropout follows Bernoulli distribution where the dropout probability is a stepwise function of queue length or current wait time. If the current waiting time is under 30 minutes, there won't be any drop out. With increasing wait time, the dropout probability will increase accordingly. Figure 3 plots the distribution of dropout probability as a function of waiting time.

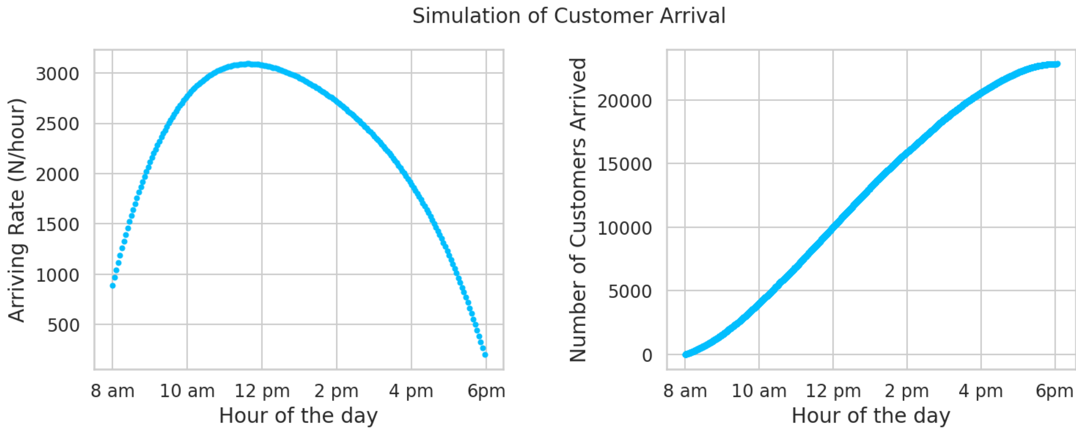

Figure 2: Simulated customer arrivals by hour of the day.

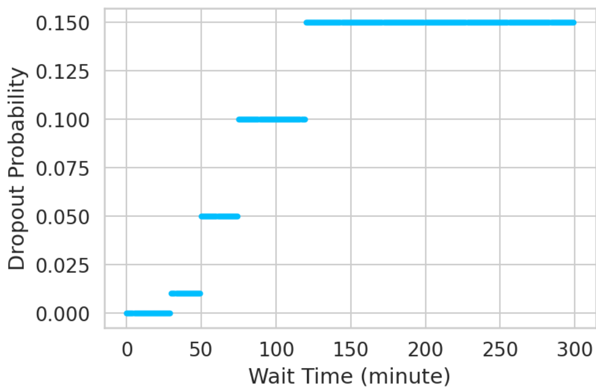

Figure 3: Dropout probability by waiting time (minute).

2.3 Customer Service

The service time contains three parts: loading time, ride time and unloading time. According to the wikipedia page of *Seven Dwarfs Mine Train*[4], there are five trains in total and each train can take 20 riders for each trip. The total duration of the ride is 2 minutes and 50 seconds. As reported in *Seven Dwarfs Mine Train Opening Day Observations*, the minimum dispatch interval (loading time) is 43 seconds while the maximum is approximately 55 seconds between trains[5]. We use the reported values above to calculate the service times.

To simply the calculation, we treat the five trains as a long train with max capacity of 100 riders per ride. Table 1 summarizes the statistics for loading, riding and unloading times. Assuming uniform distributions for loading and unloading times, The total service time can be expressed as

$$S \sim U(0.72, 1.12) + 2.83 + U(0.2, 0.4)$$

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Table 1: Serive time data for loading, unloading and ride time.

Service Phase	Mean (minutes)	Minimum (minutes)	Maximum (minutes)
Loading Time	0.72	0.91	1.12
Ride Time	2.83	2.83	2.83
Unloading Time	0.2	0.3	0.4

3 Results

The queuing system is implemented in Python using Google Colab. The source code can be found in this google colab link (click).

Figure 4 shows the calculated average waiting time over time of the day with a train capacity of 100. With daily throughput of 20,581 riders, the estimated averaging waiting time is 149.4 minutes. The waiting time is peaked at 4 p.m. with a value of 265 minutes (MORE THAN 4 HOURS!). As a reference, Figure 5 presents the predicted waiting times over a day for the Seven Dwarfs Mine Train on December 11, 2022 cited from the touringplans.com which is the only available resource online. According to Figure 5, the predicted waiting time reaches it maximum at around 11 a.m. when remains the same until 5 p.m.. The trend is consistent with our estimation where the waiting time is above the average between 11 a.m. and 6 p.m..

However, our predicted time is much larger than the posted waiting time. It can be caused by several reasons. Firstly, We estimate the daily attendance of Seven Dwarfs Mine Train to be 22,000. However, given an average service time of 4.05 (loading+unloading+riding) and the train capacity of 100 riders, the total number of customers it can serve is at most 15,000 within 10 hours opening times. Thus, the actual number of guests can be lower than what we assumed in this project.

Second, in above simulation, we assume a constant train capacity. In real word application, the train capacity may vary depending on the crowd level of the attraction. For instance, during peak hours, additional trains can be added to reduce customer waiting times. Dynamically adjusting train capacity can lead to a decrements in waiting time. To simulate the waiting times with varying train capacities. We assume the normal train capacity is 100. After 11 a.m., the train capacity is increased to 120 riders per train and after 2p.m., the train can take at most 140 riders. Figure 6 shows the predicted waiting time with dynamically adjusted train capacity. The average waiting time is reduced to 100 minutes from 150 minutes in Figure 4. The waiting time is peaked at 3 p.m. with a value of 170 minutes.

Thirdly, these are two queuing scenarios in Disney World, the 'waiting-in-line' scenario and the 'ticket-holding' scenario. A guest can either wait for their turn in a line, following a walking-standing-walking pattern, or obtain a ticket from the ticket management system and wait until their turn comes. With the ticket-holding system (a.k.a. FastPass), customer waiting time can be greatly reduce.

In addition to above reasons, it is also possible that the touringplans.com is incorrect in their predictions. Obviously, the prediction in touringplans.com is a very rough estimation as comparing to our results.

4 Conclusion and Future Works

In this project, we are working on developing a queuing model to simulate the waiting times of the Seven Dwarfs Mine Train at Magical Kingdom, Disney World. Consistent with resources online, our predicted waiting time is below average between 8 a.m. and 11 a.m. and is peaked at 3 p.m. . The peaked value is dependent on crowd level and train capacity. Our model can provide a much more in detail prediction of waiting times of attractions in Disney World as comparing to commercial softwares online.

Based on our prediction, the amusement park can dynamically allocate their resources to better serve customers such as the number of employees supporting the visitors, and technical and operational aspects of the ride. Customers can also plan ahead before their trip. For instance, if a family wants to visit Seven Dwarfs Mine Train, they should try to avoid the peak hours around 3 p.m..

To improve our estimation, there are following future works:

1. Collect more data on customer arriving times on different days to better simulate customer arrivals.
2. Implement the FastPass system via priority queue. We expect the introduction of FastPass can reduce the average waiting times but increase the waiting times for customers in normal queues.
3. Extend the model to simulate other attractions within Disney world.

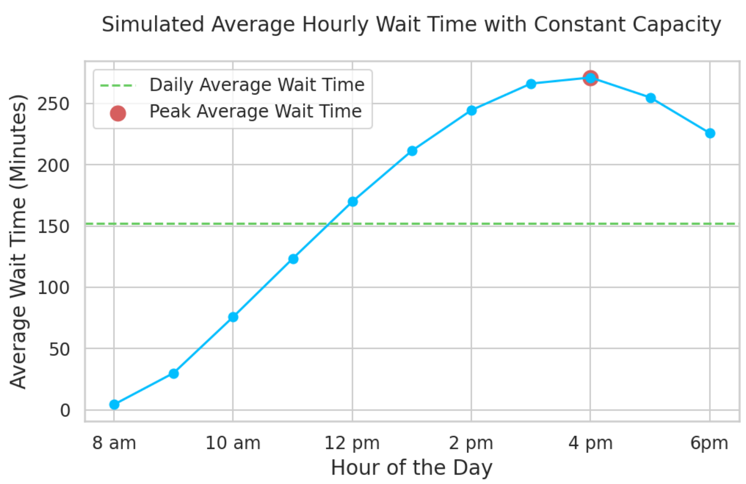

Figure 4: Simulated average waiting time with constant train capacity.

Figure 5: The posted waiting time for the 7dwarf on touringplans.com

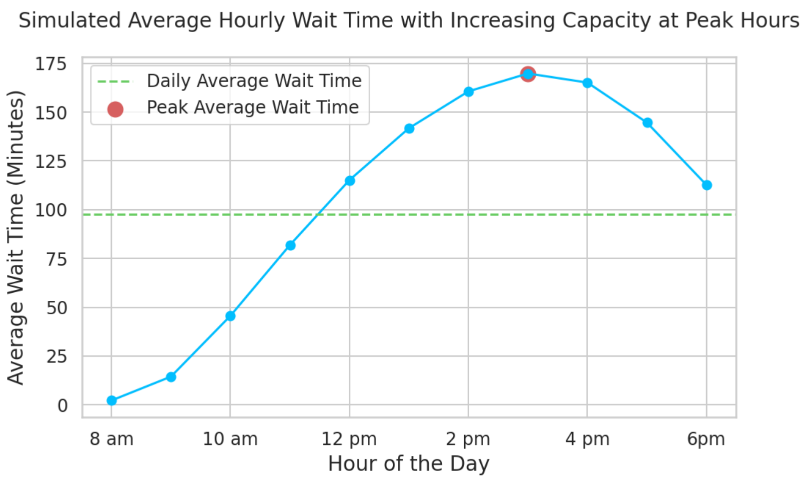

Figure 6: Simulated average waiting time with increased train capacity during peak hours.

References

[1] Katz, K (1991) *Prescription For The Waiting-In-Line Blues: Entertain, Enlighten, And Engage..*

[2] Dealing with Magic Kingdom Crowds, *https://dadsguidetowdw.com/magic-kingdom-crowds*

[3] Cohen et al. , Optimization of amusement park queuing system, *https://github.com/clandgrebe/amusement-park-queuing-optimization.*

[4] Seven Dwarfs Mine Train, *https://en.wikipedia.org/wiki/Seven-Dwarfs-Mine-Train.*

[5] Seven Dwarfs Mine Train Opening Day Observations, *https://touringplans.com/blog/seven-dwarfs-mine-train-opening-day-observations/.*

[6] Lewis, PA W and Shedler, Gerald S (1979), *Simulation of nonhomogeneous Poisson processes by thinning.*