Analysis of Alternative Queue Systems in Simulated Amusement Parks

by

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ABSTRACT

This thesis seeks to analyze the effects of alternative queueing systems on guest welfare in amusement parks. Many parks have implemented these systems, allowing some guests to skip the traditional lines for attractions. This project entailed building an amusement park simulation system, permitting analysis of five common alternative queueing systems. Numerous trials were run across a varied set of facility types. In each system type, the guest access and attraction capacity fractions were varied to gain insight into the systems. Output parameters relating to guest welfare were compared between systems, and extension options for the simulation were provided, leaving room for growth in another iteration of the project.

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1. Introduction

As the popularity of amusement parks grows, the length of the queues in parks follows suit. With new attraction wait times pushing the ten-hour mark (Webster 2019), many parks have implemented systems to reduce the amount of time guests spend in queues. These alternative queueing systems typically have a similar structure. A second queue runs in parallel to the normal queue, with the alternative queue requiring a pass for access. These passes are obtained through systems included with park admission or by purchasing them.

Implementing alternative queueing systems has an impact on how much guests are able to do at a park. With access to passes, a guest may be able to experience more attractions during their visit. However, the presence of an exclusive system can reduce the amount a guest without access is able to accomplish. The purpose of this paper is to study the impacts of these systems on overall guest experience.

2. Amusement Park Simulation Model

Amusement parks, in the broadest sense, consist of park guests interacting with attractions in the facility. This simulation is similar. In each trial, a new set of guests is randomly generated. They then step through time experiencing attractions for a set quantity of time. Four trial parks were made, each with a unique set of attractions and path layout.

2.1 Attractions

The fundamental unit of the amusement park is the attraction. Attractions in real parks are extraordinarily varied, spanning from thrilling roller coasters to spectacular shows. In this project, to reduce the diversity in attraction types, three attraction styles are used, each correlating with how guests wait for and leave the attraction.

Queued attractions are any attractions where guests are actively waiting in a line for an experience with continuous dispatch. Most traditional rides fall into this category. Time attractions dispatch guests in bulk at predetermined times. Most live entertainment fits in this category. Finally, free capacity attractions can hold a large number of guests simultaneously for continuous amounts of time. Swimming pools and museum-style exhibits are examples of this style.

Each attraction is reduced to a small feature set. The primary values driving their operation are related to capacity and duration. In queued attractions, the guest flow rate per minute into the attraction defines the capacity. These attractions also have determined values for the cycle time, how long is spent once in the attraction, and the minimum queue time, how long a guest must be waiting, at minimum, before boarding the attraction. Queued attractions, if able to breakdown, have a mean time to failure and a mean time to repair. Each minute the attraction has a chance of swapping between being open or broken with the inverse of these properties as the probability. Time attractions have a set number of guests per dispatch. Similar cycle and minimum wait times to those in queued attractions are defined. Finally, they have a set of dispatch times, as these attractions only dispatch at certain times. The properties of free capacity attractions tie in closely with guest decision making, so they will be discussed below. Additionally, all attractions have a location in the park, indicating which node the attraction is found at in a network of the park's paths. This network is fairly small, with the number of nodes sitting under ten.

2.2 Guests

The guest model for this simulation is a simple choice algorithm, with guests attempting to gain as much utility in as little time as they can. Utility is primarily gained by using attractions. At park startup, each guest is initialized with a set of stochastic utility values for each attraction that is unique to them. Each attraction has two hidden properties, a positive mean utility U_A and a thrill rating T_A, with magnitude less than one. The mean utilities are chosen to reflect the typical wait time of similar attractions (Bull 2022). Each guest has their own thrill preference, T_G, drawn randomly between zero and one. The distribution of T_G is non-uniform, favoring values close to the edges of the range more, and preferring the high end over the low end. For each guest, the utility gained at each attraction is set with a random normal drawing with parameters as follows.

$$\mu = U_A \cdot \min(1.5 - |U_A - U_G + 0.5|, 1)\,, \sigma = \frac{U_A}{3}$$

The scaling factor multiplied by the attraction's mean utility ranges from zero to one. For a guest with a low thrill preference, high thrill attractions will have reduced utility and vice versa. An attraction with a thrill rating of zero does not get impacted.

After experiencing an attraction, a guest's utility gained at that attraction will change. The new value is normally drawn with the mean at four fifths of the original utility and the standard deviation at two fifths. This is set up so that marginal utility is generally diminishing, but a random positive experience could boost the result. For free capacity attractions, utility only changes after some quantity of time is spent in the attraction, with this parameter unique to the attraction.

Free capacity attractions have an additional parameter causing utility to be decreased with increased guests present. With capacity C and G guests presents this multiplier M is defined as follows. This value sits close to one for most G < C, but reduces to a half at G = C and continues to zero beyond.

$$M = \frac{1}{1 + e^{\frac{G-C-200}{100}}}$$

When a guest is unoccupied, they look over all attraction options and select based on the ratio of gained utility to time. The time spent at an attraction depends on the attraction type. For queued attractions, this includes walking to the location, waiting in line, and the cycle time of the attraction. At timed attractions, guests use the time until the next available event ends. In free capacity attractions, the utility reducer, M, above is included with walking time to the attraction, W, and the time guests can spend before their utility at the attraction changes, t_U, to get an effective time spent value.

$$t = \frac{W + t_U}{M \cdot t_U}$$

If a guest is able to gain passes to alternative queues at queued attractions, they will use the utility per time savings to compare getting a pass to experiencing an attraction outright. With the total experience time through the normal and alternative queue being t_n and t_a, this savings can be represented as a bulk time spent, t_b.

$$\frac{U}{t_b} = \frac{U}{t_a} - \frac{U}{t_n} = U \cdot \frac{t_n - t_a}{t_n \cdot t_a}, \quad t_b = \frac{t_n \cdot t_a}{t_{n-} t_a}$$

In addition to enjoying attractions, guests have a few non-attraction options. They can use the restroom, purchase food, or purchase merchandise. Guests have need for these that increases linearly over time. When one of these need values overtakes the best attraction per time option, the guest will spend time reducing the relevant need.

Guests arrive at the park randomly as well, with close to 20% of the target population arriving at open and the remainder distributed exponentially through the day. Guests may also elect to leave at any point if they have no utility per time options above a certain threshold.

2.3 Park Models

Four test parks are used to test these systems, all loosely modeled after real world facilities. Park one is a typical United States regional theme park. It features only queued attractions, many of which have a high thrill rating. Similar parks see annual attendance a bit north of three million a year (TEA/AECOM 2019), equating to thirty thousand a day given their seasonal operation schedule. Park two is a mid-sized waterpark. It contains queued attractions and free capacity attractions, representing water slides and pools. Waterparks at this scale can see upwards of four hundred thousand guests a year over a similar seasonal operation schedule, yielding four thousand on a typical day. Park three is a theme park with a live entertainment focus. It contains both queued attractions and time attractions. Similar parks tend to operate at a capacity point around twenty thousand a day. The final park, park four, is a wildlife park. It features all three attraction types and operates at a very high capacity. With year-round operation an average day can sit at forty thousand guests.

2.4 Baseline Simulations

To establish a point of comparison to the alternative queue options that follow, a set of baseline simulations were run with no alternative queues.

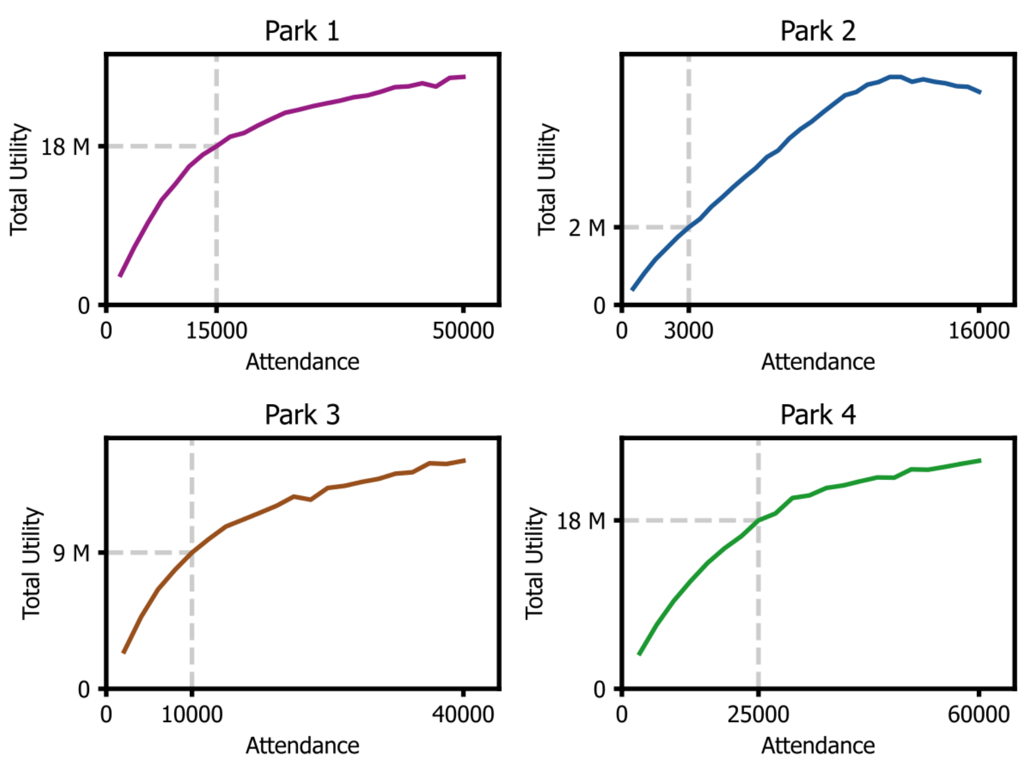

Figure 1: Total utility gained by all guests as a function of park attendance for the four simulated parks. The dashed lines indicate the population size of the remaining simulations.

First, each park was run over a range of appropriate guest attendance values. For each park and attendance, the total utility gained and the average utility per guest were calculated. The total utility typically increased with attendance, but diminishingly. All attractions have either limited guest throughput or a utility that diminishes with more guests present. Once all seats are filled, an increase in attendance continues to keep this total increasing, as a larger population will have more guests able to gain more utility from those seats. In the case of park two, the total utility begins to decline at a point. When the numerous free capacity attractions at this facility overfill their utility output diminishes, causing a drop off.

The mean utility of all guests strictly diminishes as a function of population. Park two has an abnormally shaped curve, again caused by the high quantity of free capacity attractions in the park.

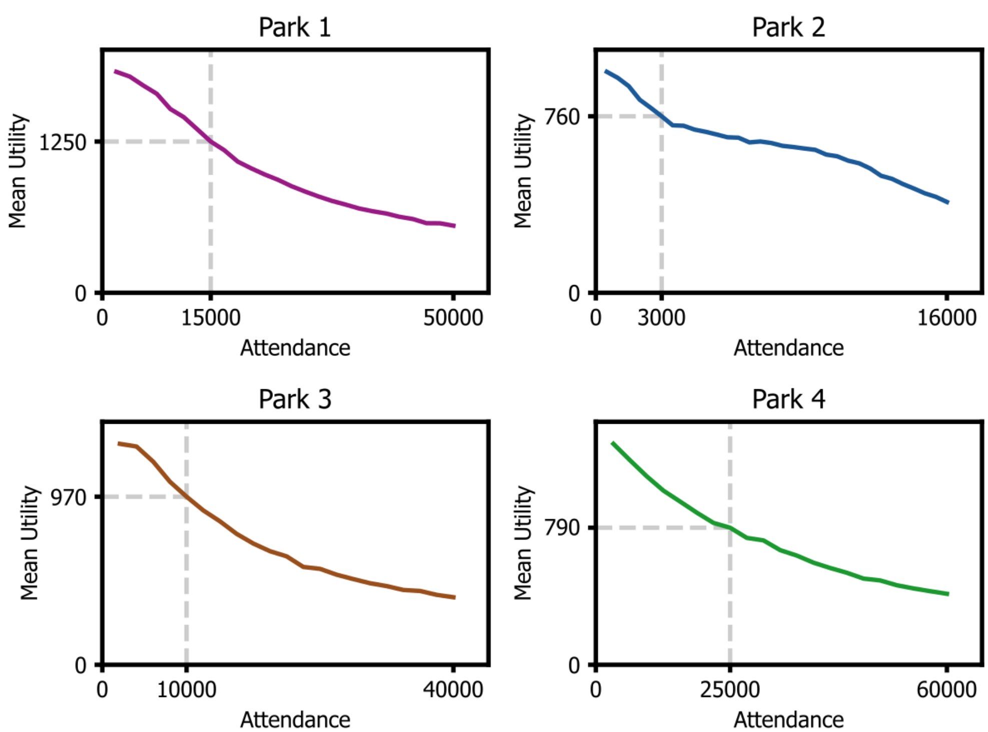

Figure 2: Mean utility among guests as a function of attendance in the four simulated parks. The dashed lines indicate the population size of the remaining simulations.

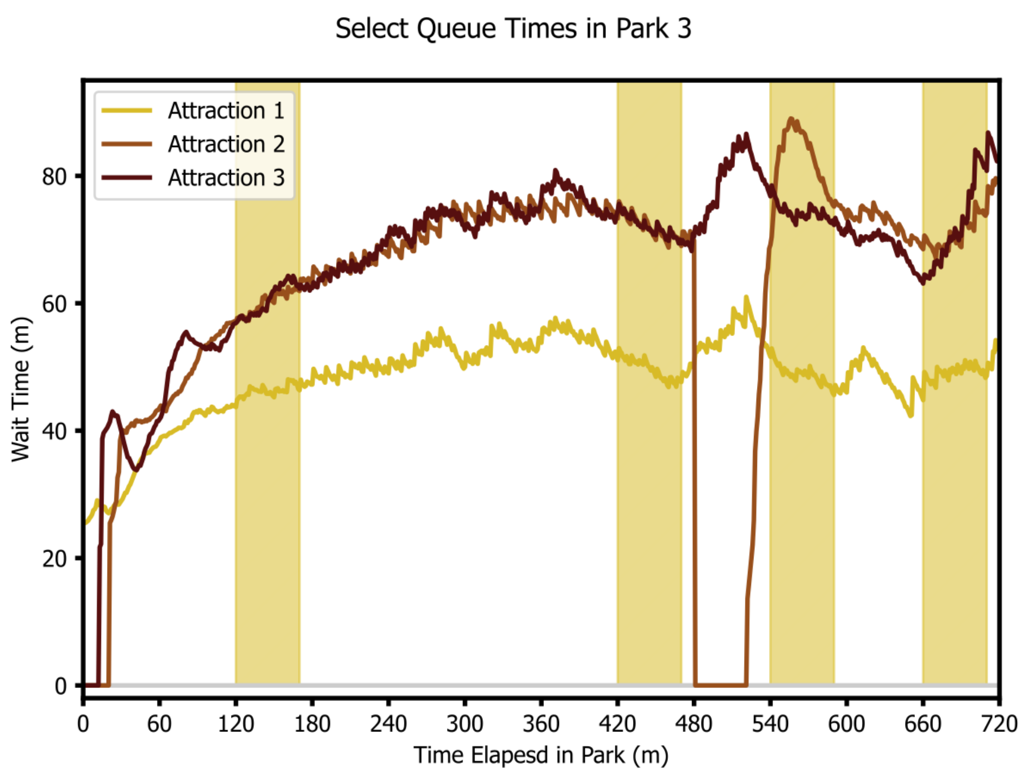

Figure 3: Queue times of select attractions in park three. The yellow bars indicate time attractions taking place during the day.

Inspecting the queue times in the parks as a function of time can yield more insight into the simulation's behavior. Looking at a run of park three, a few interesting effects are visible. In Figure three, attraction one is located near the time attraction, a popular show, with dispatch start and end times indicated in yellow. Prior to the show starting and during the duration of it, the three attractions shown tend to have a decrease in wait time. Attraction one sees a bump in wait time after the event, as many guests become unoccupied near it once the show ends. Midway through the day, attraction two encounters a breakdown, causing its queue to be evacuated. The influx of unoccupied guests spikes the wait times of other attractions. Once the attraction is repaired, it sees a boost in its own wait time for a time. In park four the impacts of the park's night show are visible. Before it begins it attracts guests and diminishes wait times around the park. Attraction one, located nearby, sees a small hop after the show begins. Many guests walk to the show's location but are turned away if the capacity is full. Looking to their other options, attraction one is nearby, causing this small deviation. It also sees a sizeable increase after the show ends.

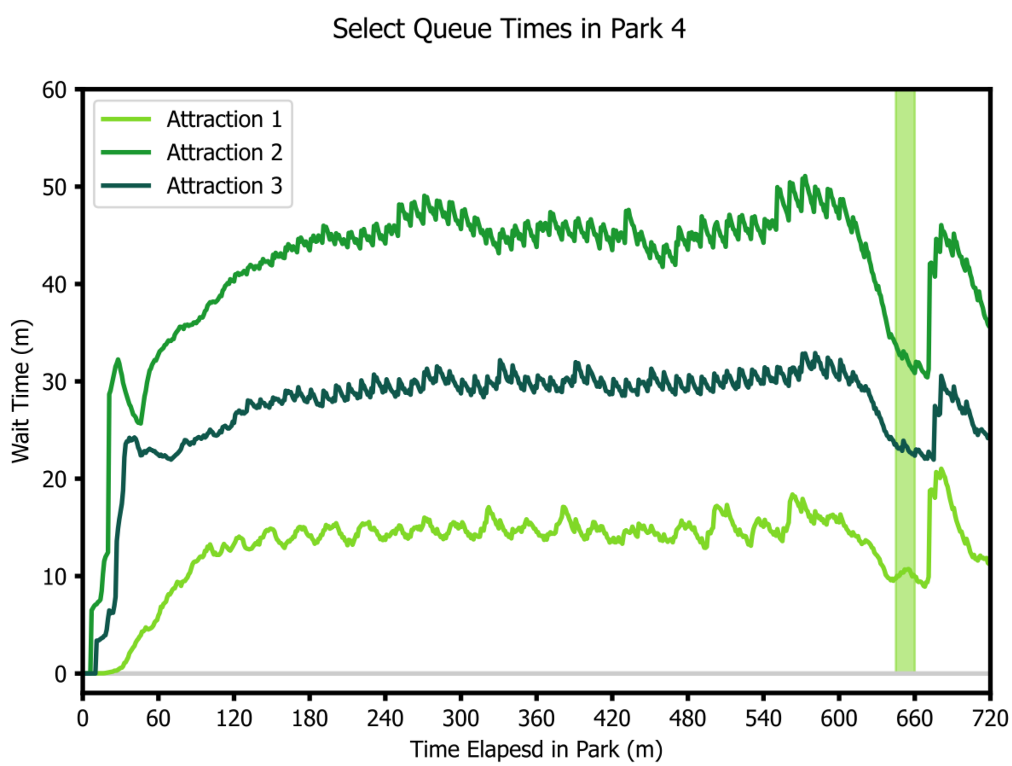

Figure 4: Queue times of select attractions in park four. The green bar indicates a popular time attraction occurring.

Simulations where the guests were given inaccurate, rounded, or delayed wait time values were omitted, as they have been studied in length (Daw, Nirenberg and Pender 2018).

3. Alternative Queues

When implemented, alternative queue systems provide means for guests to effectively skip lines. In these systems, an alternative queue exists in parallel to the normal queue in queued attractions. To gain access to the alternative queue, different systems behave differently. Some systems require payment to access while others come included with park admission. Across all systems however, some fraction of guests will have access to the system. Once guests are in the two queues, most systems behave similarly. The alternative queue is devoted to some fraction of a ride's capacity, and the remainder goes to the normal queue. These two quantities, the guest fraction and the capacity fraction, provide a base spectrum to analyze these systems. Each pass type was simulated over the range of these two values to study these general outcomes.

3.1 Wristband Passes

The first alternative queue option looked at with this simulation is wristband passes. In parks with this system, guests may purchase a wristband, allowing them access to an alternative queue. These guests are either given full priority over the regular line, or merged with the regular line at the capacity fraction prior to dispatch.

At a glance, this system can provide extreme benefit to guests with access, notably when the guest fraction is low and the capacity fraction is high. However, the mean utility among all guests in the park is lower than in a park without this system implemented unless the guest access fraction is fairly low. Wristband passes are suited well to be a luxury option, offered by the park to gain more income from guests that highly value their time or their attractions.

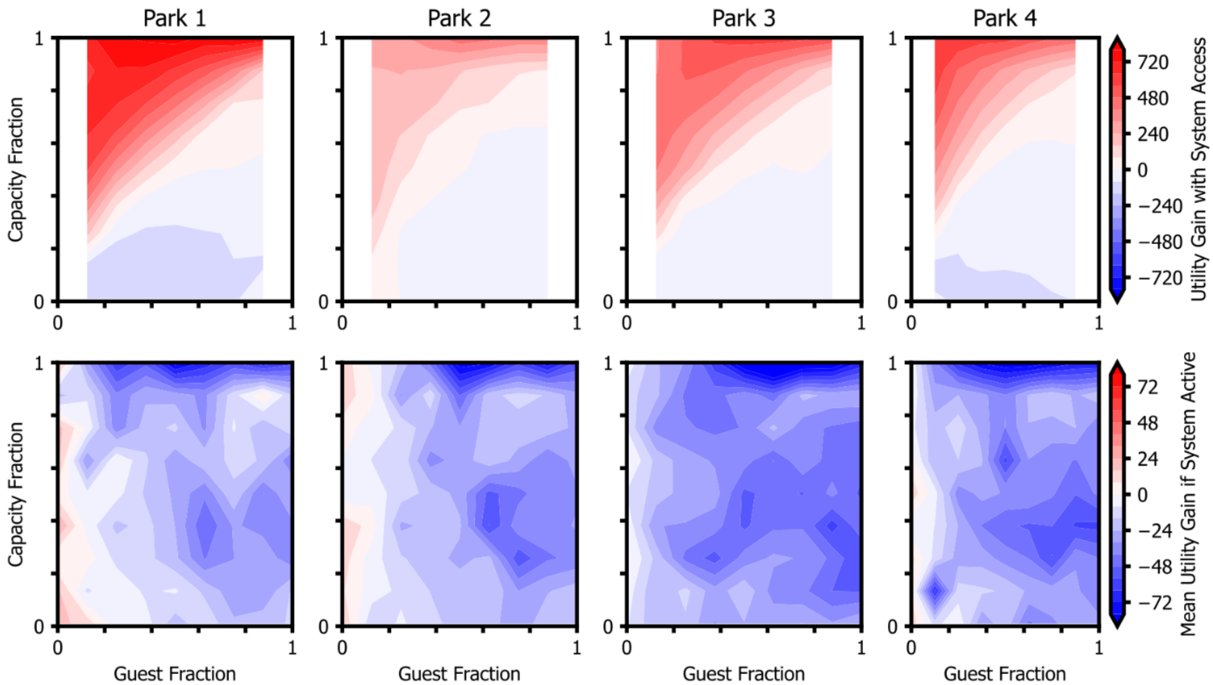

Figure 5: Difference in utility between guests with and without wristband passes shown above. Difference in utility between the average guest in a park with this alternative queue system active and inactive below.

3.2 One-Time Passes

Another common alternative queue system is similar to the wristband pass above, except it can only be used at each attraction once. These passes provide a much less extreme benefit to guests than wristband passes do. These passes though, retain their value better than wristband passes as the fraction of guests with them increases, with a shallower angle across the gain with access graphs. The mean utility among all guests with this system active is typically below the mean without the system active, with exception when the guest access fraction is low. One-time passes sit in the same category as wristband passes above, beneficial as a luxury option.

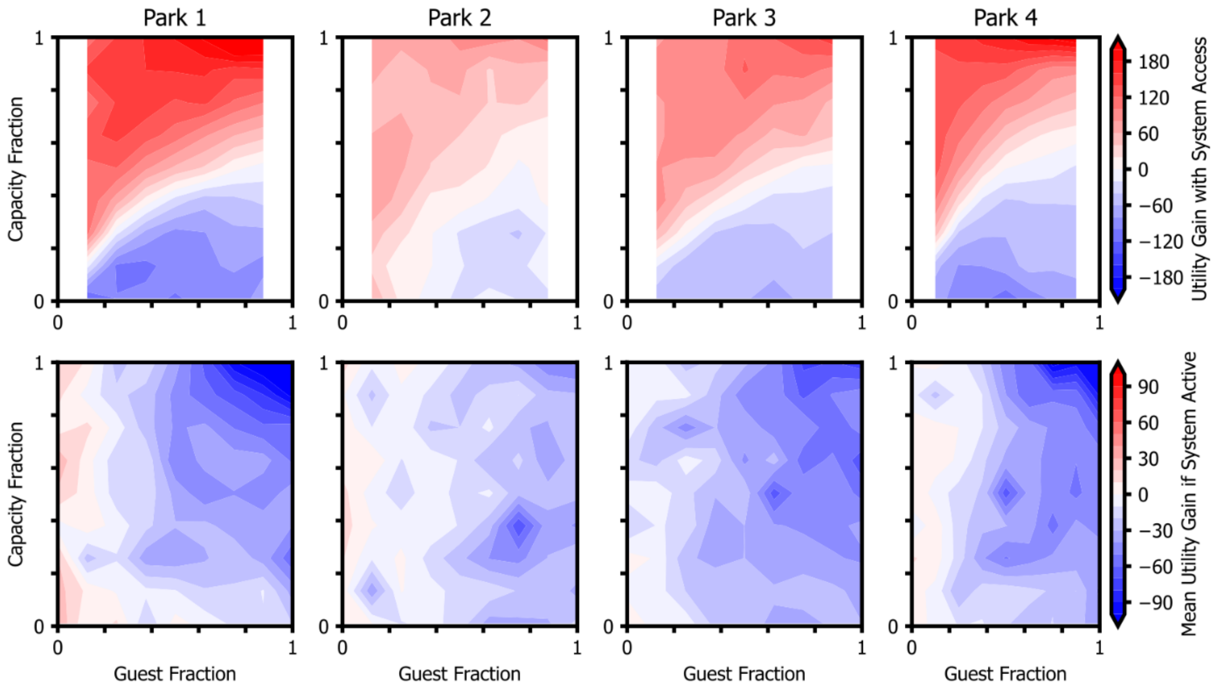

Figure 6: Difference in utility between guests with and without one-time passes shown above. Difference in utility between the average guest in a park with this alternative queue system active and inactive below.

3.3 Return Passes

An extremely well-known alternative queueing system is Disney's FastPass. This system in the simulation is highly inspired by FastPass. In the park, guests with system access are allowed to pick up return passes at select attractions. At the pick-up kiosks, guests scan their admission ticket and receive an additional paper return pass with two times printed. The return time, when the guest may visit the attraction through the alternative queue, and the time when the guest my obtain another return pass are both listed.

The return time for the attraction is tabulated incrementally, with the time bumping up five minutes every so many passes taken. This quantity is determined by the target number of guests through the alternative queue, the attraction's expected capacity multiplied by the alternative queue's merge ratio. The time when the guest can obtain another pass is either the return time or two hours from the time the last ticket was taken, whichever is smaller.

When giving only some guests access, the region where those guests benefit the most is fairly steep compared to the other options. When more guests get access to the system, more passes are taken and fewer pass options remain, making the system less beneficial. The mean utility in the park is also closer to the mean without this system implemented, especially in parks one and two.

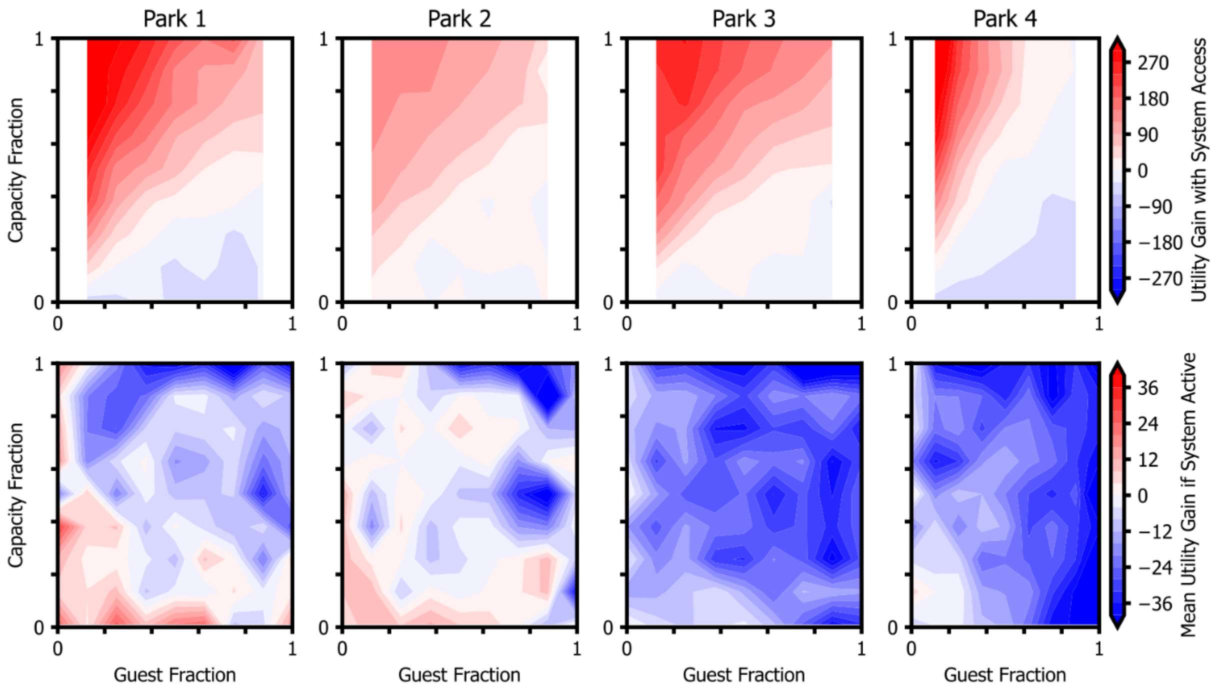

Figure 7: Difference in utility between guests with and without access to return passes shown above. Difference in utility between the average guest in a park with this alternative queue system active and inactive below

3.4 Virtual Electronic Passes

In this alternative queue system, some guests may use mobile electronics to reserve a single attraction return time at a time. Each attraction's return time is a fraction of its normal queue's wait time. This fraction is the same across attractions in a park. When the return time comes up, the guest may enter the attraction's alternative queue with full priority over the normal queue and reserve their next attraction.

In this system, the capacity fraction represents the percentage of the wait time the guests in the system spend waiting outside the queue. This inverts the typical capacity fraction graphs from above, causing a lower value to benefit guests with system access more. The impact on overall guest utility becomes greater primarily when more guests have system access. Even with low wait time fractions, the total system utility gets fairly close to the baseline with a low guest access fraction.

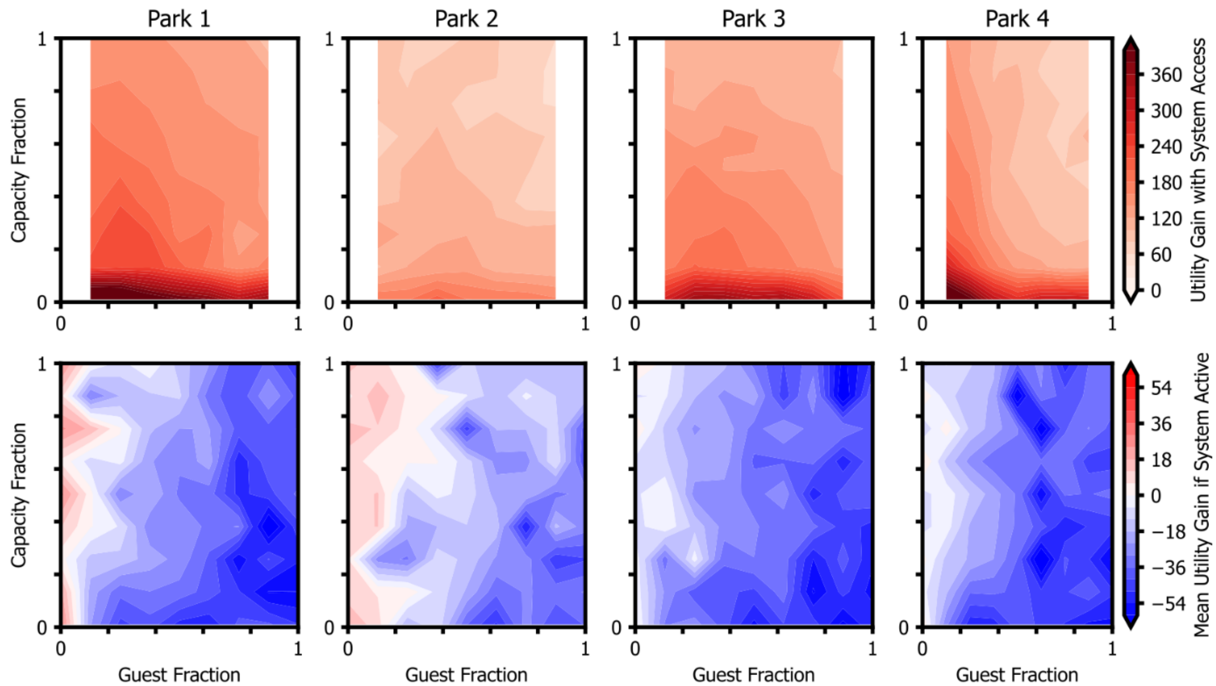

Figure 8: Difference in utility between guests with and without access to virtual electronic passes shown above. Difference in utility between the average guest in a park with this alternative queue system active and inactive below.

3.5 Pre-Reserved Passes

This system behaves similarly to return passes above, except they are all pre-reserved prior to the park opening. The total ride capacity to be allocated to alternative queues is tabulated and divided by the number of guests getting pre-reserved passes, to get the number of passes each guest can take. Each guest in order then selects their passes based on where they can get the most gain in utility per time. Using the formula for utility gain from taking tickets, we can approximate the time spent in the attraction if using the alternative queue with the minimum queue and cycle time added. The time spent in the normal queue can be approximated by the guest's utility, as utility is linearly proportional to the average queue times given our setup. When maximizing, as the second term tends to unity, only the guest's utility and time spent in the alternative queue are relevant.

$$\frac{U}{t_b} = \frac{U}{t_a} - \frac{U}{t_n} = \frac{U}{t_a} - \frac{U}{U}$$

These passes give consistent guest benefit. As in prior systems this benefit it greater when more attraction capacity is given to the system and fewer guests have access to the system. Pre-reserved passes are less impactful on total guest utility than other systems, with the effects only being prominent when the guest fraction and capacity fraction are high. This system is the best example of a system that can operate without much utility loss at a high guest fraction.

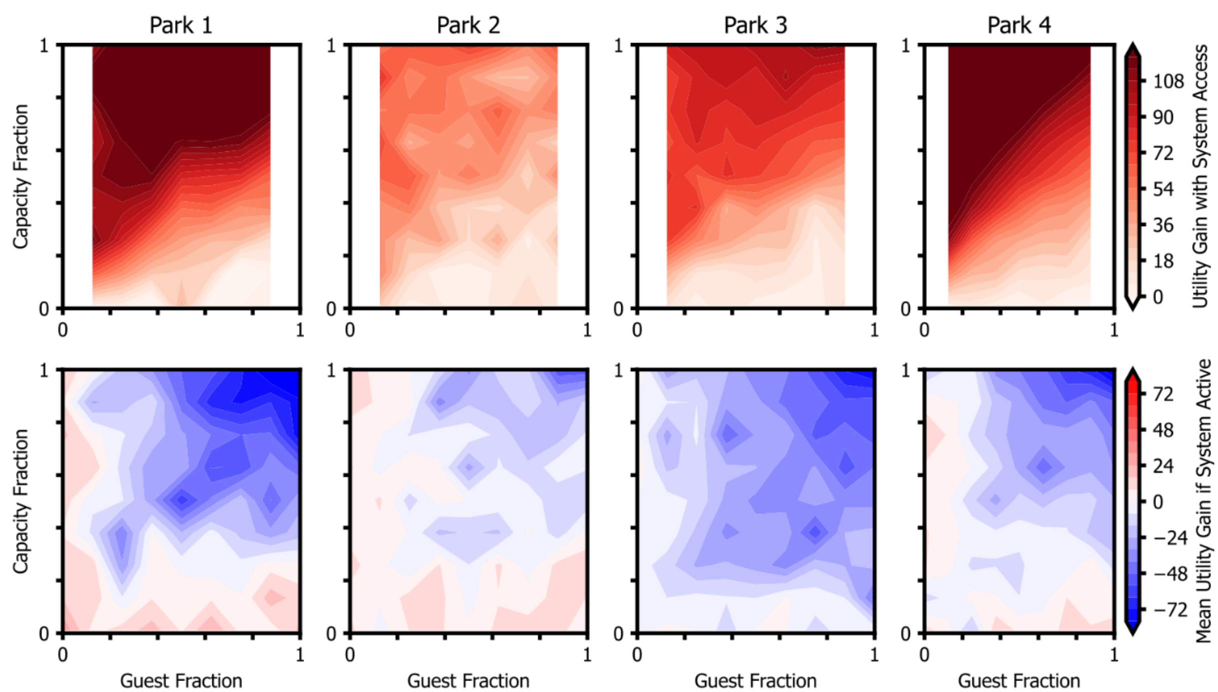

Figure 9: Difference in utility between guests with and without pre-reserved passes shown above. Difference in utility between the average guest in a park with this alternative queue system active and inactive below.

3.6 General Conclusions

To generate simple comparison points, each alternative option above was run at the same guest access fraction of one eighth and capacity fraction of one half. For guests with system access, the best system for them is clearly wristband passes. The limited restriction on attraction access provided is unrivaled among these systems. For overall guest utility, one-time passes and return passes preformed well. Only one pass system preformed better than the no system baseline, return passes in park three. These systems studied, overall, do not pull more utility out of the system as a whole.

Table 1: Mean utility of guests with and without system access, as well as the mean utility among all guests. All simulations were run with one eighth of guests having system access and half of attraction capacity devoted to the system.

Park	1			2			3			4		
No System	1255			766			964			791		
Guests Averaged	No Access	System Access	All Guests	No Access	System Access	All Guests	No Access	System Access	All Guests	No Access	System Access	All Guests
Wristband	1157	**1720**	1228	723	**941**	751	899	**1285**	947	727	**1085**	772
One-Time	**1232**	1359	**1248**	746	810	754	**953**	1037	963	**772**	892	**787**
Return	1216	1468	1247	**749**	855	**762**	944	1157	**971**	747	949	772
Virtual Electronic	1219	1416	1242	741	837	753	947	1081	963	754	927	776
Pre-Reserved	1230	1351	1245	748	806	755	952	1035	962	761	896	778

All five of these systems had additional parameters studied yielding minimally interesting results. The number of food and merchandise purchases changed minimally across all systems. The amount of queueing space required, a linear function of the maximum number of people in each queue, was very similar in all systems.

The parks were tested at lower attendance. At the current operating point, near utility saturation, the total system gain is resistant to change. With less guests in the park, unutilized seats could become filled due to effects from alternative queueing systems, increasing total welfare. The results from testing at half the prior capacity showed minimal system improvement. Nearly all systems had less total utility than the runs without a system in place.

Table 2: Mean utility of guests with and without system access, as well as the mean utility among all guests. All simulations were run with one eighth of guests having system access and half of attraction capacity devoted to the system. Parks had half of their capacity from prior simulations.

Park	1			2			3			4		
No System	1611			907			1230			1026		
Guests Averaged	No Access	System Access	All Guests	No Access	System Access	All Guests	No Access	System Access	All Guests	No Access	System Access	All Guests
Wristband	1585	**1808**	1613	870	**956**	882	1210	**1330**	1225	945	**1297**	989
One-Time	1593	1638	1600	**901**	918	**903**	**1228**	1237	**1230**	1001	1083	1012
Return	1600	1700	1612	891	893	891	1208	1260	1215	988	1202	1014
Virtual Electronic	**1605**	1683	**1615**	900	910	901	1210	1211	1210	**1008**	1126	**1022**
Pre-Reserved	1599	1637	1603	895	907	897	1219	1247	1223	1004	1088	1014

The guest modeling used contributes greatly to these results. Changes could possibly yield more interesting results. In reality guests typically exist as a group, a complexity that was removed for this project. When making decisions as a group, utility is lost if any guest does not get their optimal choice. These guests also had minimal forward thinking, only looking for the best option now. Factoring in expected future wait times could be a healthy next step. The guests also had fairly perfect information. Their given wait times and utilities were accurate, making each decision the best decision. Including more variability in guest information could modify system behavior.

Having correlation between guest utility properties and pass access could also make results more interesting. A guest who greatly enjoys attractions will get more benefit out of access passes. They would also be more likely to purchase them, as they can get more utility compared to others. As a facility, running multiple price points could capture a greater number of customers at a level where more profit can be generated.

4. Conclusion

While alternative queueing systems are becoming popular at many theme parks, their impacts on overall guest welfare range from negligible to negative. At lower capacities, virtual electronic systems and one-time passes provide minimal decreases to overall utility. Offering one of these systems as a luxury could generate additional profit without severely impacting the remaining guests. Pre-reserved passes offer minimal reduction in welfare when a low fraction of attraction capacity is given to them, even when many guests have access to the system, making these another healthy option to generate more revenue. More study, specifically involving a more complex guest model, should be used before generating more conclusive results.

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