Dynamic Resource Allocation Systems in Large Operations: Fixing the Genie

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1 Abstract

Theme parks continuously seek to improve guest experiences by optimizing attraction scheduling and reducing wait times. Despite these efforts, existing systems such as Disney Parks' Online Fastpass/Genie+ often result in unequal experiences among visitors, with discrepancies largely based on socioeconomic status and prior knowledge of park operations. This gap allows seasoned visitors to disproportionately benefit from the parks' services, leaving less experienced guests at a disadvantage. This paper addresses the inefficiencies observed in Disney Parks' reservation and pass allocation strategies. I adapt the Vickrey-Clarke-Groves (VCG) mechanism to these systems with the purpose of allocating expedited queue passes more fairly, aiming to provide a more balanced experience for all visitors. By reforming how wait times are distributed, this study offers insights for enhancing product and operation strategies within the theme park industry.

2 Introduction

The introduction of the Genie+ service represented a shift in the management of guest flow and experience optimization in theme parks. In theory, the expedited pass system would serve to improve park operations by alleviating congestion and potentially augmenting the park's revenue, however, both empirical analysis and reports on visitor satisfaction suggest that the system does not meet expectations in terms of reducing waiting times for most park visitors, nor does it enhance the overall park experience. This has led to the creation of various market opportunities for supplementary services such as StandbySkipper—an independent, "premium" priced service that commands prices even higher than Genie+ for guaranteeing the access to certain attractions. The success of these complementary services highlights two things: 1.- There remains a demand for services that streamline the process of obtaining optimal schedules for park visits 2.- As opposed to physical systems such as paper expedited queue passes, digital interfaces are more successful in capturing broader demographics such as experienced and recurrent visitors that want to maximize their number of rides per visit, as well as one-time visitors and individuals that want to spend more time enjoying the parks without the added stress of active scheduling. Also, since the existing (and simpler) design choices that would most efficiently solve the problem of reducing standby queue wait times rely on a lack of expedited pass offerings, and therefore do not maximize revenue for the parks, the solution to the disparity in ride allocations needs to offer businesses equal or higher revenue for using their expedited pass services. Hence, the integration of new scheduling and allocation processes into theme park operations must tackle several different challenges; these include: adapting to fluctuations in visitor numbers, managing the finite supply of expedited passes effectively, as well as maximizing social welfare while handling the demands of a visitor base with heterogeneous preferences without adding undue complexity to user experience. The development of an effective method of dynamic allocation in this context will not only aim to maximize operational efficiency but also ensure that its systems simplify the potential visitor's decision-making process, minimizing the necessity of engaging with scheduling systems for park visitors with ride valuations around the mean. The success of this mechanism will be valued to the extent that it allows the greatest number visitors to experience shorter wait times while allowing ride-enthusiasts to enjoy most of the benefits of expedited queues at a fair price. This is precisely the problem that I address in this paper.

With the help of a base model of visitor dynamics, I develop a framework for the use of the VCG mechanism for FastPass+ (i.e., online expedited pass) acquisition. The model consists of various rides, each with unique characteristics and possibilities for visitor interaction:

Attractions: The environment features an array of 13 attractions designed to represent the variety of experiences available at a large, well-equipped amusement park in a smaller scale. These include: High-Capacity Rides: Inspired by large-scale rides capable of accommodating many visitors per hour. They are designed to be the backbone of the park's ride offerings, helping to absorb large crowds and reduce overall wait times. Medium-Capacity Rides: A balance between thrill and accessibility, modelled after haunted houses, themed attractions, and interactive experiences that offer high entertainment value but have moderate throughput capacities. Exclusive Experiences: The lower-capacity, high-demand attractions of modern theme parks such as VR experiences, escape rooms, or guided tours that offer unique experiences but can only serve a limited number of guests at a time. They often require advance booking and may cater to niche interests. Key Attributes of Attractions include Run Time: The duration a single cycle of the ride or experience takes from start to finish. Hourly Throughput: The number of guests an attraction can handle in one hour. Popularity Index: Based on real park data. This index affects how likely it is that an agent will choose a certain ride given they decide to not perform a different activity. Expedited Queue Options: Allowing visitors with expedited passes to reserve their spot for a later time without remaining in a standby queue (similar to the original paper FastPass system). Eligibility Criteria: Based on visitor demographics such as height, age, or health conditions. In the model, almost all rides are designated as child-friendly.

Agents: Visitors in the amusement park are represented as agents. Each agent is designed to mimic the diversity of actual park visitors in terms of their behavior, preferences, and decision-making processes. The simulation categorizes these behaviors into distinct archetypes to try and capture the broad spectrum of visitor types typically encountered in real-world settings. Each behavioral archetype is a composite of several attributes that dictate how an agent interacts with the park environment. These attributes include: Preference for Ride Thrill: Defining how much an agent values the rides. Agents with a high thrill preference are more likely to try their luck at more attractions, and stay in the park for longer, those with lower thrill preferences might opt for both rides and other activities to different degrees. Wait Time Sensitivity: Measuring an agent's tolerance for waiting in line. Agents with low wait time sensitivity are willing to endure longer queues for rides they perceive as worth waiting for, whereas those with high sensitivities prefer attractions with shorter wait times and gravitate towards purchasing expedited access.

Adaptation of the Auction Mechanism and Outline

To address the management of FastPass distribution, I adapt the Vickrey-Clarke-Groves or VCG auction mechanism to the model simulation. The approach was chosen for its efficiency in allocating limited resources (the expedited passes) among increasing numbers of competing agents (park visitors) while ensuring truthful bidding. In order, I define a Pre-booking Phase: Visitors can purchase expedited passes up to 30 days before their park visit. Each ride offers a limited number of expedited passes per day, sold through a bidding process; inspired by real-life data from large amusement parks such as Disney, a greater number of "experienced" agents were modelled as bidders for earlier dates, with this number decreasing until the ticket's true date; I compare the results of the model both with and without this assumption by letting higher agent valuations naturally dictate the feasible allocations of the passes in a different instance of the auction***. Auction Process: At the end of each day, for each time slot of each ride, the expedited passes are bundled in distinct categories and awarded to the highest bidders. The number of passes available per slot (k) is predetermined based on each attraction's characteristics. The Pricing Strategy: Winners of the expedited passes pay the price bid by the highest unsuccessful bidder (the $k+1$ highest bid), ensuring that each bidder has an incentive to bid their true valuations. And the simulation of Bidding Behavior: Agents' willingness to pay for expedited passes is influenced by their individual preferences and ride characteristics.

Agents valuation functions are weighted and depend on archetype preferences, parameters of the park environment, and a certain degree of randomness. This reflects the fact that different agents have different sensitivities to waiting times, ride-seeking, and rides have different constraints and levels of popularity, and the fact that real group preferences are usually not entirely homogeneous. After the allocations are determined, the model is subsequently ran with the appropriate parameters to accurately represent the distribution of winning bidders, the expedited passes are assigned to each individual agent and further purchase is restricted. The simulation tracks the metrics for each visitor as usual, including total attractions visited and overall wait times.

Metrics: Visitor Throughput: Measures the number of rides completed per visitor and per hour. Queue Times: Analyzes the distribution of wait times across all visitors with and without expedited passes.

*Park statistics recorded by external sites such as ThrillData and TouringPlans seem to corroborate the existence of a skewed distribution where a diminishing segment of visitors disproportionately access the majority of rides at major attraction parks such as Disney, hence, and since the virtual model reflects this accurately as well, I base my final conclusions on its results.

3 Methodology

3.1 Relevant Archetype Parameters

$$\text{Agent Behaviour}(i) = \begin{cases} \text{stay time preference} & \text{Normal}(\mu, \sigma) \\ \text{allow repeats} & \text{Binary} \\ \text{ride preference} & p \\ \text{wait threshold} & \theta \end{cases}$$

Where μ and σ are derived from the archetype's defined mean stay time and its variance. p represents the probability of preferring rides over activities. θ is the maximum acceptable waiting time threshold for the agent before attempting to get a FastPass.

$$\text{Choose}(i) = \begin{cases} \text{Ride} & \text{if } u < p_{\text{ride}} \\ \text{Activity} & \text{otherwise} \end{cases}$$

Where u is a uniform random variable $u \sim U(0, 1)$. p_{ride} is the agent's preference for rides over activities.

$$\text{Queue Decision}(i, r) = \begin{cases} \text{Expedited} & \text{if } W_r > \theta_{\text{expedited}} \text{ and available} \\ \text{Standard} & \text{otherwise} \end{cases}$$

Where W_r is the waiting time for ride r at time t. $\theta_{\text{expedited}}$ is the agent's expedited wait threshold.

$$Q_{t+1}(r) = \max(Q_t(r) + A_t - C, 0)$$

$$E_{t+1}(r) = \max(E_t(r) + A_t^e - C^e, 0)$$

Where $Q_t(r)$ and $E_t(r)$ are the standard and expedited queue lengths for ride r at time t, respectively. A_t and A_t^e are arrivals at the standard and expedited queues at time t, respectively. C and C^e are the capacities for standard and expedited access.

3.2 Relevant Park Characteristics

The arrivals are given by

$$A_t = \text{Poisson}(\lambda_t), \quad \lambda_t = \frac{N \cdot p_h}{60}$$

Where A_t is the number of agents arriving at minute t. N is the total number of agents expected for the day. And p_h is the percentage of agents arriving during hour h. λ_t is the expected number of arrivals per minute. The distribution of arrivals is adapted to the setting of the study.

Rides handle both standard and expedited queues:

$$Q_{t+1}(r) = \max(Q_t(r) + A_t - C, 0), \quad E_{t+1}(r) = \max(E_t(r) + A_t^e - C^e, 0)$$

Where $Q_t(r)$ and $E_t(r)$ are the lengths of the standard and expedited queues at time t, respectively. A_t and A_t^e are arrivals at the standard and expedited queues at time t, respectively. C and C^e represent the capacities for standard and expedited access, adjusted by the ride's throughput and run time.

$$\text{LoadGuests}(r) = \min(\text{capacity}, |Q_t(r)|), \quad \text{ExpLoadGuests}(r) = \min(\text{capacity}\cdot\text{expedited queue ratio}, |E_t(r)|)$$

Standard and expedited guests are loaded based on their respective queue lengths and the ride's capacity constraints. When it's time for an attraction to start a new cycle, it loads agents from both the standard and expedited queues according to their capacities:

$$\text{Load}(r) = \begin{cases} \text{Load from standard queue:} & \min(\text{capacity} - \text{expedited seats}, |Q_t(r)|) \\ \text{Load from expedited queue:} & \min(\text{expedited seats}, |E_t(r)|) \end{cases}$$

3.3 The Mechanism

I assume additive valuations and define the individual functions according to:

$$V_{(a,r,t)} = \alpha \times P_r + \beta \times (R_a + W_a) - \gamma \times B_i + \delta$$

Where:

- $V_{a,r,t}$: Valuation of agent a for an expedited pass of r during time slot t
- P_r: Popularity of the ride
- R_a: Agent's preference towards the ride
- W_a: Agent's wait time threshold for the ride queue
- B_i: Time-dependent bundle of expedited passes
- δ: Random term introduced to incorporate a degree of unpredictability, it ensures that agents with the same archetype are able to place unique valuations.

Pre-booking Phase: The weights α, β, and γ are set and the distribution of expedited passes and their supply per slot is defined as $\frac{C^e}{\#bundles}$ over n.

Auction Process: For simplicity we round up to integer valuations and offer the individual expedited passes with no strict slot specifications. This allows us to minimize envy later on given the assumption that $B_{(a,i)} \geq B_{(a,i')}$ for all agents a and $i \neq i'$, explicitly: agents weakly prefer their bundle over any other (so they would rather ride the attraction at any time that is offered in their bid bundle over a different one) and adjust the distribution of goods according to park predictions of visitor congestion, I define time bundles for the morning, afternoon, and evening in this particular instance. Given the complexity of finding every feasible allocation in the auction for large numbers of visitors I rely on the selection of a representative sample of bids of each agent to optimize the run-time, and compare these results with approximations given by a implementation of a GA (genetic algorithm) with a monotone non-decreasing objective function and an arbitrary price rule**, this step may be omitted for the purposes of determining the allocation of rides for smaller numbers of expedited passes, however. This represents the particular instance of this project, hence the short introduction.

Winning Bids and Simulation: If there exist any remaining passes, these can be added to the following day's distribution or ignored, as their addition to the next possible offerings does not significantly alter the macroscopic allocation outcome. The winners of each FastPass are randomly assigned their respective queue time after the auction given their specified bundle and after n days the simulation is ran with no other modifications.

**Elaboration on the approximation and detailing of the degree to which it maximizes social-welfare are not included in this paper, but I would be interested and happy to discuss it further as it was both an interesting and new addition to the cross-validation of the results of the auction for the simulation. Trivially, it becomes increasingly relevant as I increase the number of both rides and offerings of expedited passes given the intractability of VCG and that one of the objectives of this mechanism is to not significantly increase the cost incurred by experienced park visitors.

4 Experimental Results

The simulation is first ran as usual. It is later ran with an identical random seed taking into account the results of the auction, the statistics are tracked and recorded for comparison purposes as detailed below.

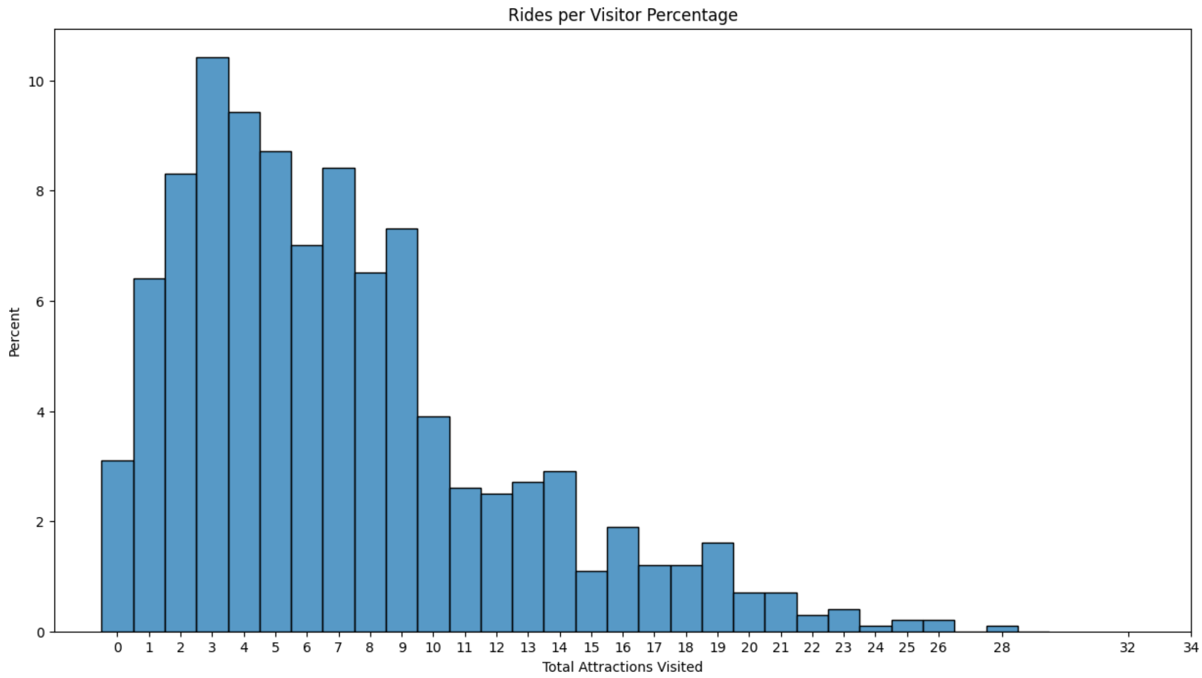

Figure 1: Attractions per Visitor - Ex-Ante Auction

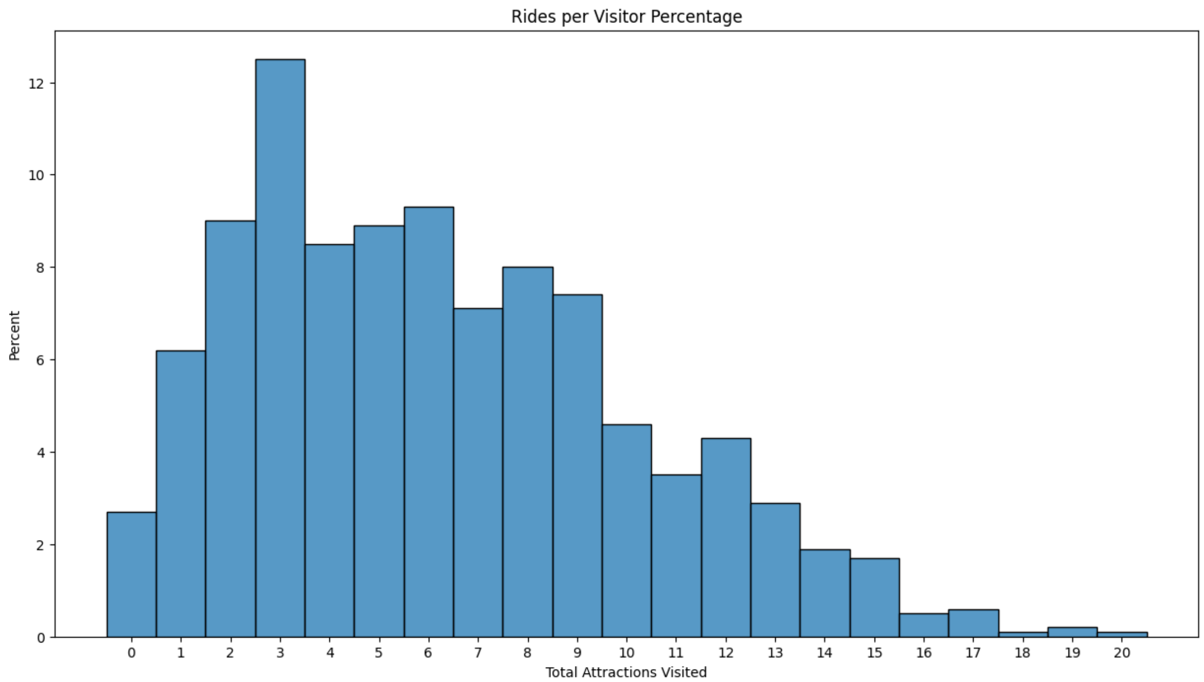

Figure 2: Attractions per Visitor - Ex-Post Auction

Arguably the most important result of the paper, indeed, as per my original assumptions it seems that the implementation of an auction mechanism in the expedited pass acquisition process allows a greater number of visitors to benefit from a larger number of experiences in the park, this particular figure focuses on rides visited.

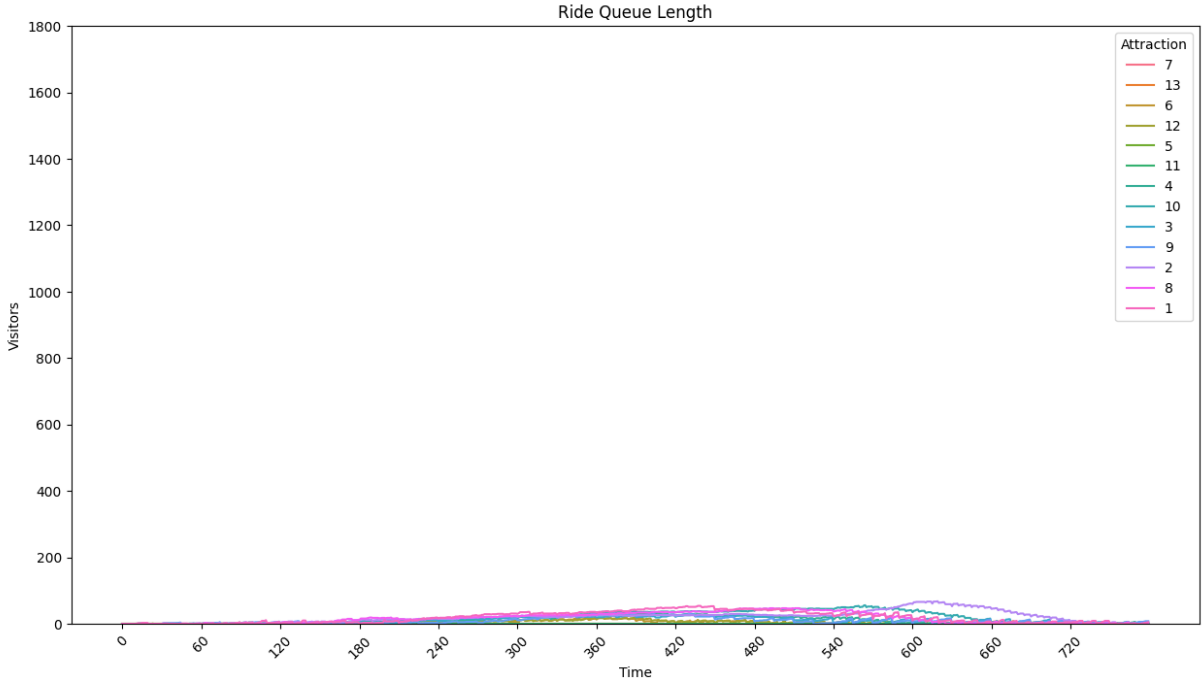

Figure 3: Queue Length for Park Rides - Ex-Ante Auction

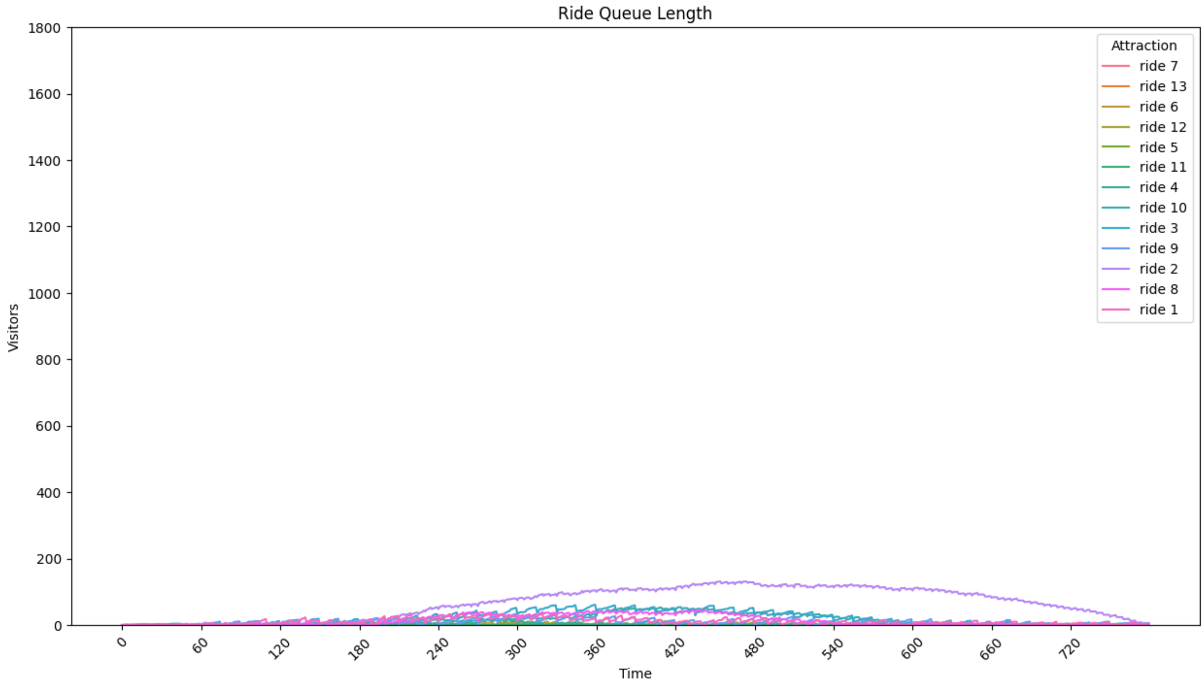

Figure 4: Queue Length for Park Rides - Ex-Post Auction

That is, for the vast majority of activities, visitors are spending less time in queues. An exception is ride 12; see below Figure 6.

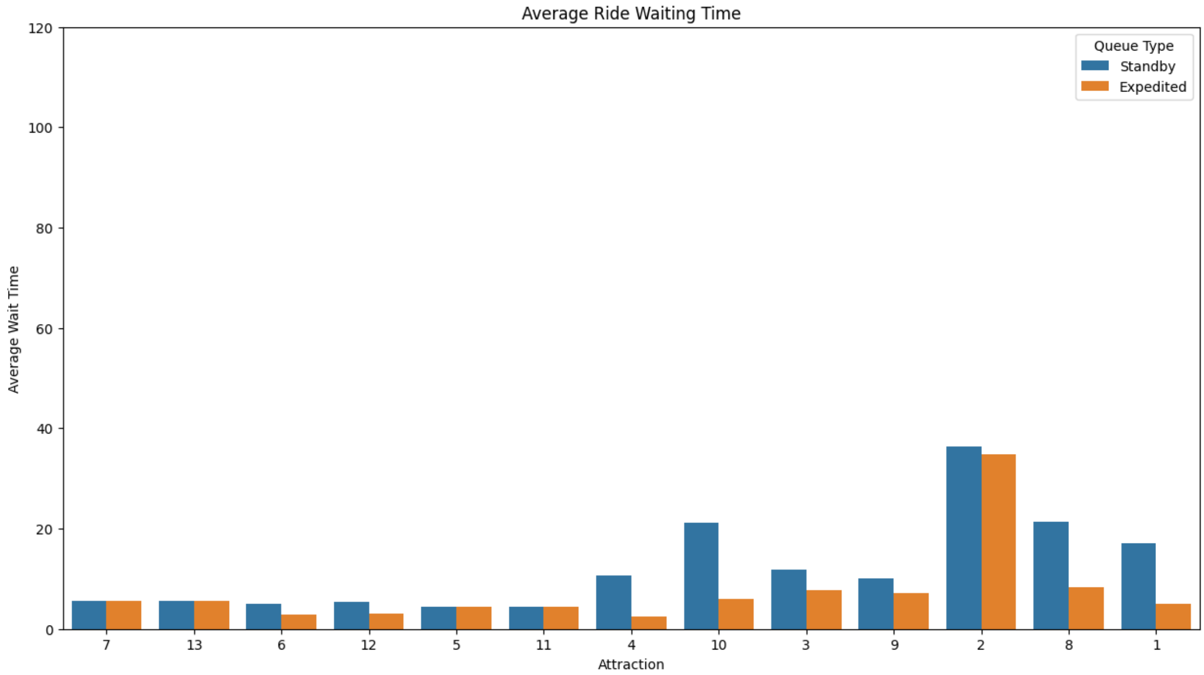

Figure 5: Wait Times Experienced by Visitors - Ex-Ante Auction

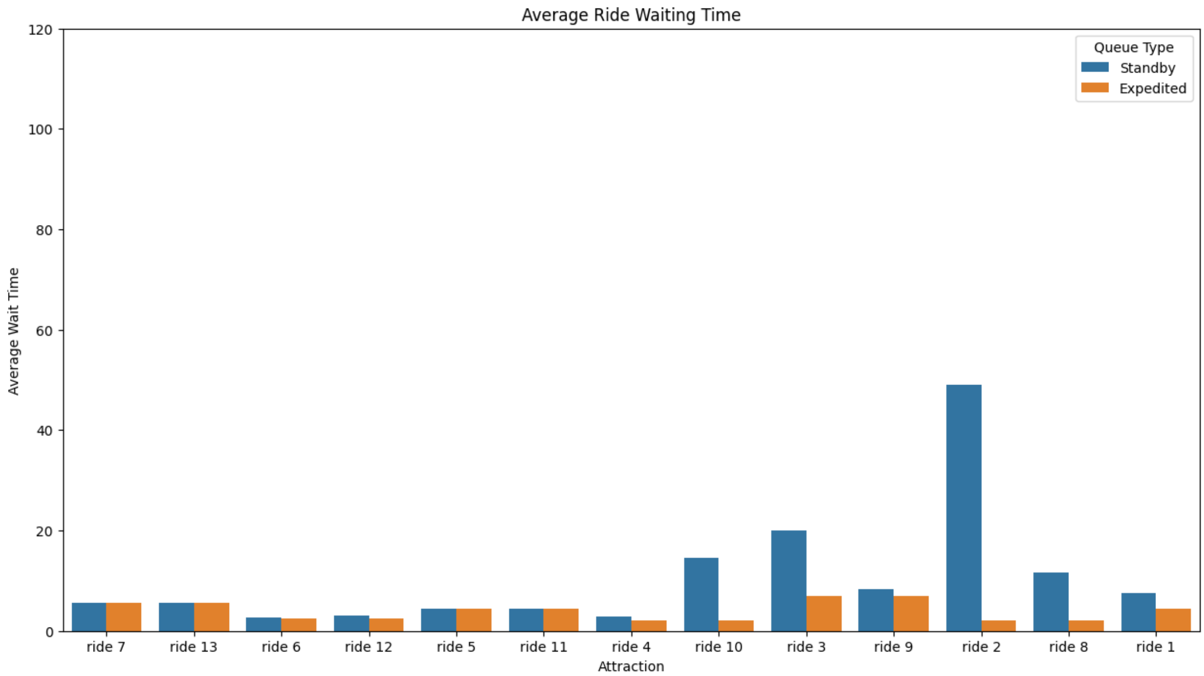

Figure 6: Wait Times Experienced by Visitors - Ex-Post Auction

A noticeable reduction in overall waiting times was found. Although at first hand the increase in waiting times for rides 2 and 3 might seem problematic, the results take on a different light once we recall that the ratio of expedited pass queue reservations per ride was not changed in the simulation model, that is, these are ride 2 and 3 expected wait times without redistributing "spots" from the now unnecessarily vast expedited pass queue, this is also noted by observing the reduction in wait times for visitors that happened to hold expedited passes as allocated by the auction.

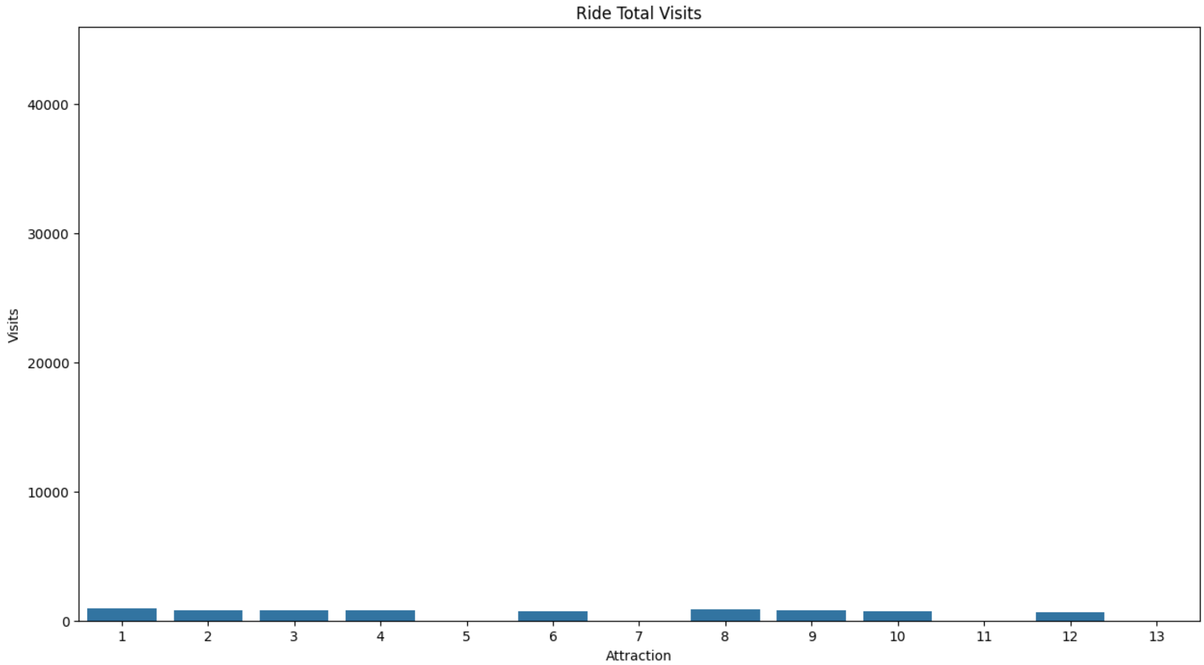

Figure 7: Total Visits per Ride - Ex-Ante Auction

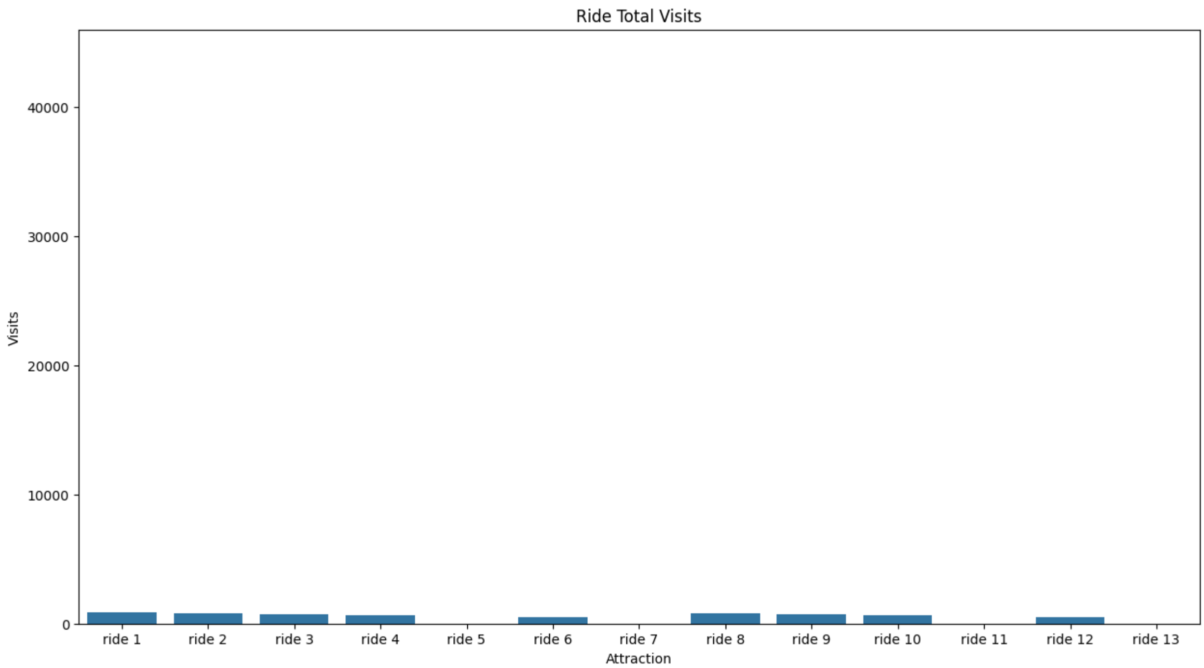

Figure 8: Total Visits per Ride - Ex-Post Auction

As expected, since the popularity and archetype parameters stayed the same throughout the experiment, the total number of visits per ride did not change significantly.

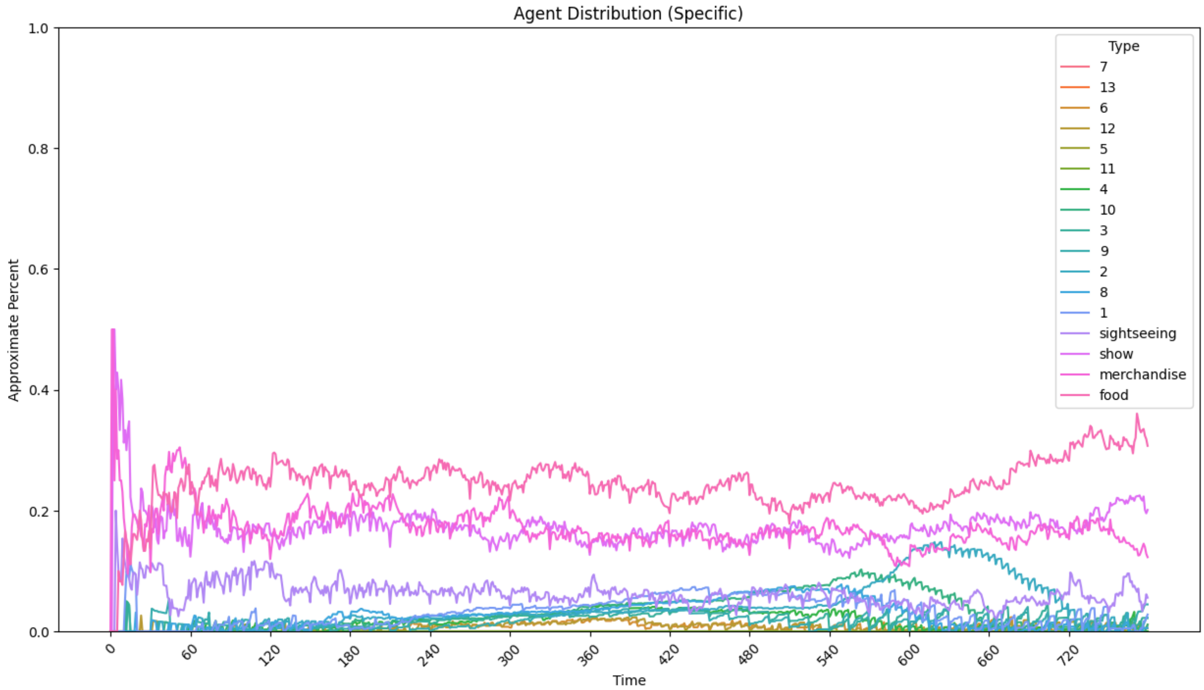

Figure 9: Distribution of Time Spent in Rides/Secondary Activities - Ex-Ante Auction

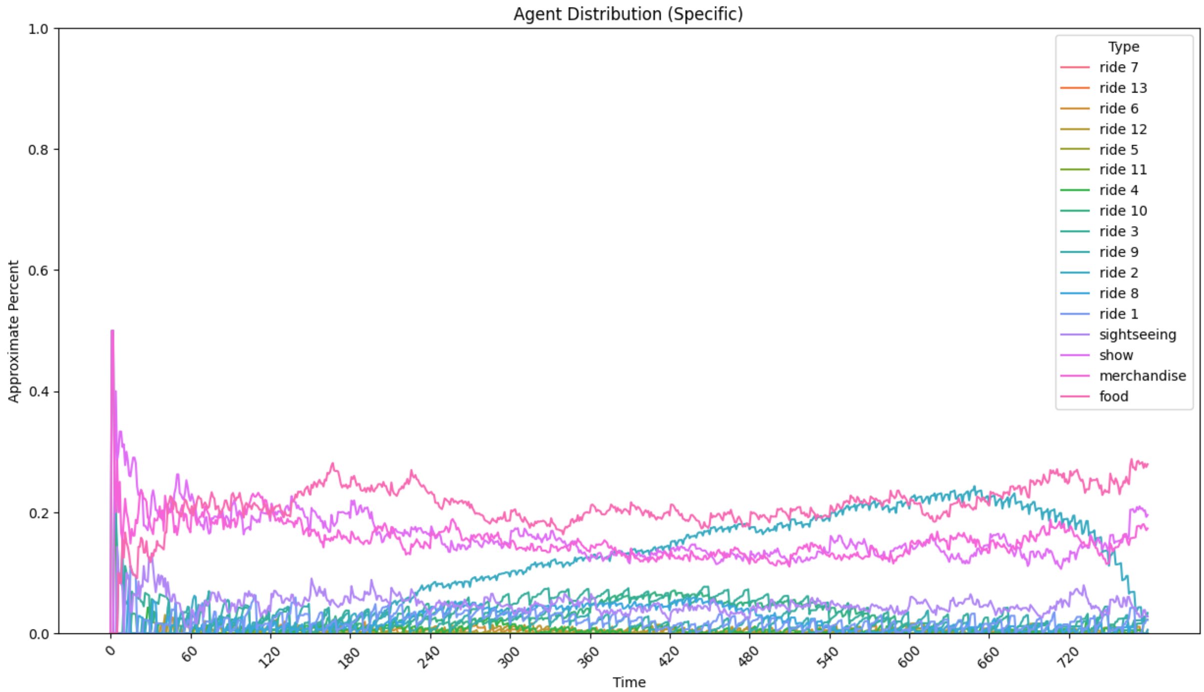

Figure 10: Distribution of Time Spent in Rides/Secondary Activities - Ex-Post Auction

A more specific view of the overall decrease in the number of visitors that spent large amounts of time in various activities.

***Both results are consistent, hence, the Ex-Post allocation figures refer to the latter. See "Outline" in the introduction section of the paper.

5 Discussion

5.1 Overview

The primary goal of this study was to evaluate the effectiveness of implementing a Vickrey-Clarke-Groves (VCG) auction mechanism for the allocation of expedited queue passes (FastPasses) in a theme park environment. The hypothesis posited that such a mechanism would reduce wait times in standby queues, thereby enhancing the overall guest experience of most visitors. The results, which demonstrate a decrease in standby queue wait times and an increase in ride throughput, support this hypothesis. This section will elaborate on the implications of these findings, potential limitations, and avenues for future research.

5.2 Implications of Findings

The implementation of the VCG auction mechanism resulted in a noticeable reduction in standby queue wait times. Specifically, the results show an average decrease in wait times of around 13 minutes for standby queues across the attractions. This reduction can be further increased by a more efficient distribution of visitors between standby and expedited queues . By ensuring that those who value expedited access the most are the ones who receive it, the auction mechanism effectively balances the load across the park, minimizing bottlenecks and improving the flow of visitors.

In addition to shorter wait times, the mechanism also led to a notable increase in ride throughput. The results indicate a 1.7 increase in the number of rides completed per visitor per hour. The improvement in throughput is crucial for maximizing the park's capacity and enhancing guest experience. Higher throughput means that more visitors can enjoy more attractions within the same number of hours spent in the park, which should lead to higher levels of overall satisfaction.

One of the key advantages of using the VCG mechanism in this context is its ability to allocate resources in a manner that is perceived as "fair" and proved as efficient. The mechanism ensures that expedited passes are awarded to those who value them the most while at the same time minimizing the cost of pass acquisition, maximizing the utility of the prospective park visitors that decide to participate in the auction process. This should not only maximize social welfare but also reduce the potential for frustration/envy among visitors who might otherwise feel disadvantaged by a first-come, first-served system for ride queueing.

5.3 Potential Limitations

The simulation model used in this study relies on several assumptions that, while necessary for feasibility, may limit the generalizability of the findings. For instance, the model assumes that visitors' valuations of rides and their willingness to pay for expedited access are accurately represented by the given archetypes. Hence, and even as these seem to be able to mimic real-world behavior accurately, they may not capture the full complexity of visitor preferences. Similarly, the visitor dynamics model does not account for external factors that may influence wait times and visitor behavior, such as inclement weather, ride malfunctions, etc. These factors can have significant impacts on park operations and guest experiences, and their exclusion from the model could represent practical concerns. Another potential limitation is the assumption that a high proportion of the visitors that currently rely on Disney's Genie+/Lightning Lane services are willing and able to participate in the auction process, since the auction component could drive a greater part of the park demographic to rely on standby queues; this however does not represent a hindrance to the desired outcomes as a significant decrease in the use of expedited passes that is accompanied by a decrease in expedited queue reservations serves the similar purpose of reducing standby wait times. Relevant simplifying assumptions include the weak preference among bundles, the expectation of "reasonable" bid amounts, highest valuations being a representative sample (given this instance's limited computational resources) and the original assumptions regarding visitor/park dynamics. Perceived fairness of the expedited pass allocation service should be measured among visitors, this could entail conducting post-visit surveys in the parks that decide to adopt the VCG system among various other methods.

5.4 Future Research

To build on the findings of this paper, there are several avenues to be explored. Further improvements or modifications to the allocation system may include allowing trades between agents post-allocation, discarding bid sampling, refining the contributions of the time-dependent terms in bidders valuation functions, extensive empirical testing, among others. Similarly enhancing the model to include more granular and dynamic visitor preferences and behaviors would provide a more accurate representation of real-world scenarios. This could involve collecting and integrating real-time data on visitor movement through the park and characterizing adaptable preferences. Finally, supporting the mechanism through learning algorithms could improve the feasible allocations without requiring visitors to report their complete preferences, and has the potential to further enhance the efficiency and ease of use of a pass acquisition services based on these methods. Research could explore the potential benefits and challenges of designing, building, and testing such hybrid models. The extent to which improving the approximations that can be given by non-deterministic algorithms may increase the feasibility of implementing computationally expensive rules and mechanisms beyond the scope of traditional combinatorial optimization problems remains an incredibly interesting topic.

6 Conclusion

The results of this study provide solid evidence that auction mechanisms can effectively reduce standby queue wait times and increase ride throughput in the settings studied. By ensuring that expedited passes are allocated to those who value them the most, the mechanism enhances both operational efficiency and visitor satisfaction. While there are certain limitations and general assumptions in the model, the overall findings support the potential of auction-based allocation systems to improve theme park experiences. Future research should continue to refine and expand upon these findings to develop even more effective solutions for managing visitor flow and enhancing guest experiences.

7 References

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8 Appendices

The code used for simulations in this study is available on GitHub here. The repository includes all scripts and instructions necessary to reproduce the results presented in this paper.

The auction process implements a modified version of a standalone VCG allocation script by Kevin Shan (2018), under the MIT License. In accordance to it, it is fully displayed in the text file in the project folder.