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Mathematical Modeling and Enhancing the Carrying Capacity of National Parks in the United States

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ABSTRACT

A rapid growth in the number of visitors has been observed for many national parks in the United States, examples include Yellowstone National Park, Yosemite National Park, Rocky Mountain National Park and Arches National Park. As a result, public transit and parking resources have been stretched closer and closer to their capacities in these parks. In response, some National Park Services (NPS) have started to implement crowd control measurements, such as the timed entry reservation systems, where visitors have to reserve their slots to visit the park during certain time periods of the year. However, such policy does not touch on the fundamental issue of the subject, that is, the carrying capacity of the park. In this paper, we demonstrate that there will be even greater growth in the number of visitors in the near future, which means that a capacity boost is inevitable. Fortunately, we also observe that if we can fix some key bottlenecks, then we can dramatically increase the capacity of the park without destroying more natural land.

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Introduction

A rapid growth in the number of visitors to America's most celebrated national parks has been observed in recent decades. Yet, said growth is disproportionately distributed among different parks. In 2022, 26% of total recreation visits occurred in the 8 most visited parks, while 25% of total recreation visits occurred in the 331 least visited parks [1]. This inequality has led to, as some claimed, management issues in these parks. They claim that more visitors would put extra pressure on the National Park Service (NPS) to preserve the natural characteristics of the park, while also leading to less satisfactory experiences for visitors coming to the park. Moreover, some national parks are located in geographically isolated regions, which means that there are less human resources and commercial services available in the near region of the national park to support the ever-growing number of visitors. In response, some NPS began to implement timed entry reservation systems, where visitors have to reserve slots to enter the park during peak times of the year, usually during summer months and weekends.

The effectiveness of such policies has since been widely debated, while some claim that timed entry has solved the issue and led to better experience by visitors and staff, some criticized timed entry as a form of unnecessary administrative intervention. In this report, we are going to find the predicted number of visitors to the national parks in the near future, using statistics from four classic national parks that would be a good sample to represent the national parks that have experienced rapid growth in number of visitors during the recent decades. They are Yosemite National Park (YOSE), Rocky Mountain National Park (ROMO), Arches National Park (ARCH) and Yellowstone National Park (YELL). We then discuss the current condition of these parks, and offer some suggestions on the future development of the infrastructure within the park to support the growth of recreational visits.

Data and Methodology

We collected the data of total recreational visits by month from the National Park Service Visitor Statistics [2]. For brevity, we list the total number of recreational visits by year only, as shown in the table below.

Table 1: Total Recreation Visits by Year Since 1979 in Four Selected National Parks

	ARCH	ROMO	YELL	YOSE
2023	1,482,045	4,115,837	4,501,382	3,897,070
2022	1,460,652	4,300,424	3,290,242	3,667,550
2021	1,806,865	4,434,848	4,860,242	3,287,595
2020	1,238,083	3,305,199	3,806,306	2,268,313
2019	1,659,702	4,670,053	4,020,288	4,422,861
2018	1,663,557	4,590,493	4,115,000	4,009,436
2017	1,539,028	4,437,215	4,116,524	4,336,890

2016	1,585,718	4,517,585	4,257,177	5,028,868
2015	1,399,247	4,155,916	4,097,710	4,150,217
2014	1,284,767	3,434,751	3,513,484	3,882,642
2013	1,082,866	2,991,141	3,188,030	3,691,191
2012	1,070,577	3,229,617	3,447,729	3,853,404
2011	1,040,758	3,176,941	3,394,326	3,951,393
2010	1,014,405	2,955,821	3,640,185	3,901,408
2009	996,312	2,822,325	3,295,187	3,737,472
2008	928,795	2,757,390	3,066,580	3,431,514
2007	860,181	2,895,383	3,151,343	3,503,428
2006	833,049	2,743,676	2,870,295	3,242,644
2005	781,670	2,798,368	2,835,651	3,304,144
2004	733,131	2,781,899	2,868,317	3,280,911
2003	757,781	3,067,256	3,019,375	3,378,664
2002	769,672	2,988,475	2,973,677	3,361,867
2001	754,026	3,139,685	2,758,526	3,368,731
2000	786,429	3,185,392	2,838,233	3,400,903
1999	869,980	3,186,323	3,131,381	3,493,607
1998	837,161	3,035,422	3,120,830	3,657,132
1997	858,525	2,965,354	2,889,513	3,669,970
1996	856,016	2,923,755	3,012,171	4,046,207
1995	859,374	2,878,169	3,125,285	3,958,406
1994	777,178	2,968,450	3,046,145	3,962,117
1993	773,678	2,780,342	2,912,193	3,839,645
1992	799,831	2,788,868	3,144,405	3,819,518
1991	705,882	2,751,781	2,920,537	3,423,101
1990	620,719	2,647,323	2,823,572	3,124,939
1989	555,809	2,502,915	2,644,442	3,308,159
1988	520,455	2,544,211	2,182,113	3,216,681
1987	468,916	2,531,864	2,573,194	3,152,275
1986	419,444	2,408,234	2,363,756	2,876,717
1985	363,464	2,248,854	2,226,159	2,831,952
1984	345,180	2,231,448	2,222,027	2,738,467
1983	287,875	2,599,006	2,347,242	2,457,464
1982	339,415	2,564,116	2,368,897	2,415,587
1981	326,508	2,911,242	2,521,831	2,516,893
1980	290,519	2,641,937	2,000,269	2,490,282
1979	269,840	2,568,530	1,892,908	2,350,782

From the table, our intuition suggests that the total number of recreation visits has been growing since 1979, and is growing quicker and quicker. The global pandemic has caused significant disruption to the tourism industry, and national parks are not spared. Nevertheless, it can already be seen from the table that the recovery is on the fast track for all four national parks selected. Since we have a large sample, we may treat our data as continuous and use functions to model the behavior of our data. The common models for approximating such data include exponential and polynomial functions. We shall, however, refrain from using exponential growth models. Since such a model would inevitably predict exponential growth, we would be proving us hypothesis under the assumption that our hypothesis is true. Instead, we use polynomials to investigate the growth of recreational visits. To accomplish this, we asked Derive6 to fit polynomials of the eighth to tenth degree to the given data, and the result is as shown below. The reason for using eighth to tenth degree of polynomials is that we want to model the data as accurately as possible, while being algebraically as simple as possible. Thus, after experimenting with polynomials starting from the second degree, we analyze the fitness of each polynomial, and we stop our analysis when we have three consecutive polynomials that fit the data accurately and display similar behaviors as the year approaches infinity. We found that polynomials of the eighth, ninth, tenth are sufficient for fitting the data from the four national parks of interest. Of course, we do acknowledge that polynomial approximations are only suitable for predicting the number of visitors in the near future, it is not possible for the number to grow to infinity at a

rate suggested by the polynomials. Furthermore, to prepare for the following discussion, we also estimated the current daily maximum carrying capacity of each park, using the maximum number of visitors ever recorded in the park in a given month, where we can find the daily maximum carrying capacity by taking the average value. This is a rough approximation, but it gives us some insight on the number of visitors that may be supported by the current infrastructure.

Table 2: Estimated Maximum Carrying Capacity in Four Selected National Parks

	ARCH	ROMO	YELL	YOSE
Maximum Capacity in a Month	238499 (June 2021)	973992 (July 2019)	1080767 (July 2021)	780728 (July 2016)
Maximum Capacity in a Day (Approximation)	7950	31419	34863	25185

Result

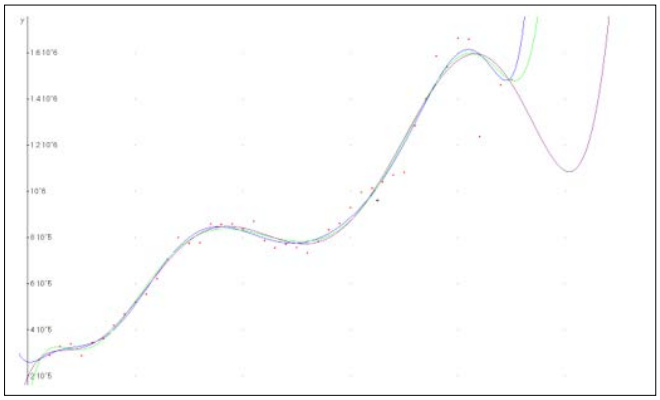

Figure 1: Total Recreational Visits in ARCH Since 1979

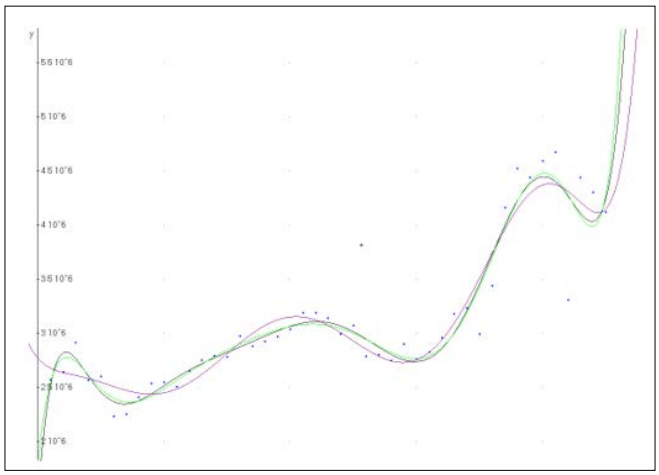

Figure 2: Total Recreational Visits in ROMO Since 1979

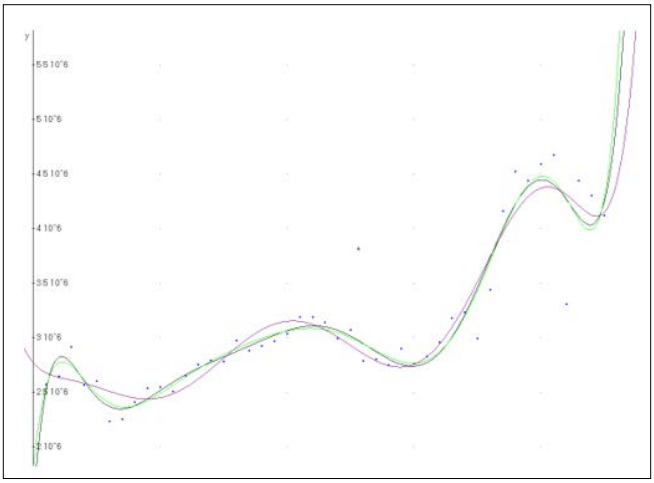

Figure 3: Total Recreational Visits in YELL Since 1979

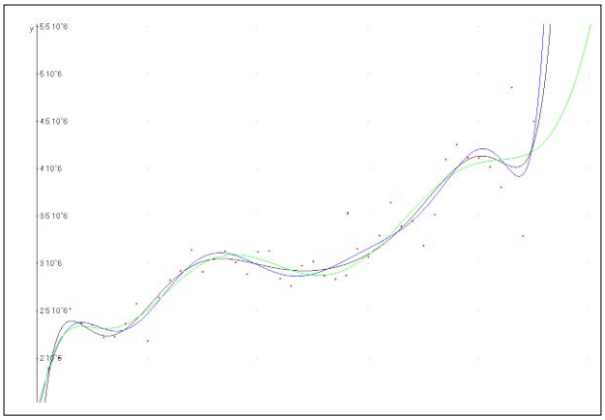

Figure 4: Total Recreational Visits in YOSE Since 1979

For brevity, we assigned number 1 to the year 1979, and all the way to number 45 for the year 2023. We are not interested in the behavior of the polynomials for negative values of t, but the behavior of the polynomials immediately right of the value t=45. This is the result of how do our polynomials predict the number of visitors coming to the four national parks in the near future. Then, we found that all polynomials predict a rapid growth of the total number of recreational visits in all four national parks in the coming years that would exceed the previous maximum values. We also want to point out that none of the polynomials in all figures touch or even get close to the outlier at t=42, which corresponds to the year 2020 when the pandemic hit the tourism industry unprepared and resulted in a sharp drop of recreational visits to the national park. This is hardly an obstacle, however, because from the data it can be seen that recreational visits have quickly bounced back since 2021. Rather, it should be seen as an advantage of our model because it smoothed out the effect of the outlier.

Discussions

The reservation system was first introduced by NPS in 2020, in response to the global pandemic. ROMO was the first national park to implement the timed entry system, although it had temporary visitor restriction measures such as metering parking lots since 2016. So far in ROMO, all timed entry permit systems are effective during summer only, from the end of May to the beginning of October. The 2020 and 2021 system in ROMO was designed to limit public use of the park (the capacity was capped at 60% in 2020 and 75%-85% in 2021), amid the impact of COVID-19; the

2022 and 2023 system in ROMO increased the number of visitors and vehicles allowed to 90% of the parking and transit capacity, which NPS claimed that it equals to approximately 20000 visitors per day. By direct calculation, it indicates that NPS estimated the total maximum capacity of the park to be 22222. This figure has a significant difference from our estimated maximum carrying capacity in the park of 31419. It is worth noting that the actual recreation visits to ROMO during the month of July 2022 were 811161, or, 26166 per day on average, which also exceeds the target capacity set by NPS. The 2024 system is expected to be roughly the same as the 2023 system, with the same capacity goal of 90%. There will be two permit systems in place, one for the Bear Lake Road Corridor, which is effective from 5 a.m. to 6 p.m.; another one for the rest of the park, which is effective from 9 a.m. to 2 p.m. ROMO is located about 70 miles northwest of Denver, a major metropolitan area with a 2020 population of 3 million people. Denver is part of a larger development area known as the Front Range Urban Corridor, which is one of the fastest growing regions in the United States, with a 2020 population of 5 million. We conclude that human resources and commercial services are easily accessible to visitors to ROMO.

Another national park that saw rapid growth in recreation visits is ARCH. Crowd control in ARCH has been in place since at least 2006, utilizing delayed entry. However, in September 2020, ARCH had to close 16 times for the sole reason of exceeding its parking capacity, a major increase from the previous years that raised some concerns. As a result, NPS introduced timed entry in 2022, which regulates the entry to the park during peak hours in summer. Only minor changes were made to the 2022 system in 2023 and 2024, with the restriction time period now set to be April 1 to October 30 from 7a.m. to 4 p.m. Despite requiring a reservation ticket, NPS warns that drivers would still need to be prepared to wait 30 to 60 minutes before entering the park. ARCH is located near Moab, Utah, which itself sits in a geographically isolated region in the United States. Moab recorded a population of merely more than five thousand in 2020.

However, it is the only town nearby for visitors to Canyonlands National Park Island in the Ski district, ARCH and numerous other world-famous recreation sites. Thus, we conclude that human resources and commercial services in Moab would be severely limited during the peak tourist season.

The timed entry system in YOSE has some major differences to the two examples discussed above. NPS introduced timed entry in 2020 as a response to the global pandemic, before removing it for the year 2023. However, the system is now reinstated for 2024. Timed entry management in YOSE is more complicated. A reservation is required for three weekends in February, where the Horsetail Fall, event is expected to attract many crowds in a relatively small area near the Horsetail Fall.

Hence, the reservation for February is required 24 hours of the day whenever the reservation is required. Then, during spring and fall, from April 13 to June 30 and from August 17 to October 27, reservations are required for entries at weekends and public holidays. Between July 1 and August 16, reservations are required every day. These restrictions apply to peak hours only, which are defined to be 5 a.m. to 4 p.m., thus covering more times of the day than ARCH or ROMO. YOSE sits in Central California, the most populated state in the nation. It is within a day's drive from most population centers in California. Nevertheless, the access roads to YOSE are all winding mountain two-lane roads, which made the park less accessible. We conclude that human resources and commercial services are moderately accessible to visitors to YOSE.

YELL is the sole example discussed here that has not implemented a timed entry reservation system yet. Nonetheless, as the first national park established in the United States, YELL is one of the most well-known tourist attractions both domestically and internationally. As a result, it has also seen a huge growth of recreational visits during the recent decades. YELL also located in an isolated region, being very far away from major population centers. Moreover, most parts of YELL only open for general recreation for a limited period of the year, roughly from the end of April to the end of October, which means that tourists who wish to experience the park have no choice but to come during peak seasons. Thus, there exists a number of small towns surrounding the park that have a significant amount of population and activity only during the time which the park opens, while being almost empty during other times of year. Limited snow recreation activities have been developed in these towns; however, the scope is nowhere near its summer crowds. We conclude that human resources and commercial services are accessible to visitors to YELL, but during peak season only.

With a basic understanding of the characteristics of the four national parks, we now turn into some suggestions on how could NPS change its operation and management procedures to adopt the growth of visitors. It is apparent that the timed entry reservation system, while definitely necessary as a means of crowd control, is not sufficient to meet future demands. More has to be done to cater for the recreation demand while preserving the natural characteristics of the park.

Suggestions

Our suggestions are based on a fundamental principle that we may not take more land from the park to develop the infrastructure to increase the capacity of the park, thus preserving the current space revered for wildlife in the park. We offer suggestions from three perspectives: dynamic pricing of entry fees, increasing capacity of public transit and built multi-level car parks. Each strategy would be used for a particular park that has suitable conditions for applying such a strategy. We will illustrate how this could be done through examples of the four national parks discussed above.

Dynamic pricing refers to a peak season surcharge in addition to the standard entry fee, which the annual pass holder must pay as well. This surcharge may vary depending on the day of entrance. In ARCH, we observed that there is always a huge disparity in recreational visits by month. In the least busy month, January, there are only as little as one tenth of visitors in the park compared to the busiest months of June and July. Yet, people who choose to come during peak season would, at most, pay $2 (which is the current reservation fee) more than people who come during shoulder season. In the recent decade, the actual difference in visitor numbers (between the least busy and the busiest months) has never dropped below 120000, which equals to nearly a tenth of total visitors per year. Therefore, if we can "smooth the curve" by directing the growth to less busy periods, then the park could handle more visitors every year with no change to any infrastructure, and hence requiring no capital investment.

Likewise, in addition to the peak season surcharge, a shoulder season discount may also be offered as an extra incentive for visitors to come during quieter seasons.

Anyway, the goal is to distribute the number of visitors as equally possible for every month, or even every day. In this sense, dynamic pricing has its similarities with timed entry reservation system. However, the latter is an administrative intervention, and may be unfair to people who lack convenient internet access; while dynamic pricing may not only be more fair, but also bring extra revenue to NPS, which may be used to improve park infrastructure.

In addition to varying the standard amenity fee, a surcharge to enter a particular area within the park may also be a useful measure on some occasions. In February, there is a special event near Horsetail Fall in YOSE. The Horsetail Fall, if it is flowing, may glow orange (akin to the color of fire) during sunset times under feasible conditions.

This popular event has attracted many visitors to come to a relatively small area during a short period of time, thus putting pressure on NPS to effectively manage the crowd. We suggest that NPS may add an extra fee to access the region to view the event during such time period. The fee may be more expansive during weekends, and even more during the only long weekend in February, the Washington Day. A separate fee to access a particular area within a United States national park is not an unprecedented action, Great Basin National Park, for example, requires a separate ticket to visit Lehman Caves [3]. Hence, there is no huge difficult to implement such a policy. The extra fee also means more revenue coming to NPS, which could again be used to improve park infrastructure.

We have mentioned that NPS in ROMO releases reservations based on the public transit and parking capacity in the park. In particular, the Bear Lake Road corridor, which leads to some of the most scenic trails in the park, attracts huge crowds every year. The corridor is so popular that a separate reservation system is developed specially for the corridor. The system, while effective in crowd control, does not increase the capacity of the corridor. We suggest that a rail transport system to be built on the road. The rails would be laid out on the road directly to ensure that NPS or other authorized vehicles could still drive on the road, but public use of the road is prohibited, at least during high-demand seasons. The railcar should be purposely built and integrated into surrounding environments to make the railcar an attraction itself. The maintenance could have taken place during quiet times, when the public would be permitted to drive on the road. Currently, Zion National Park has such arrangements on Zion Canyon Scenic Drive, but it uses buses to transport visitors whenever public use of the road is prohibited [4]. The bus shuttle system, however, frequently results in long wait times and requires more staff to operate. A railway purposely built for recreational needs is not a new concept, either. Australia has built an Alpine railway in the Kosciuszko National Park (which is also in a geographically isolated region) to cater for snow recreation activities during winter [5]. The railway itself is isolated from the rest of the rail system and traverses through some very difficult terrains. Yet, it has proven to be a huge success that removes cars from higher elevation, potentially more dangerous areas, while effectively supporting the growing demand for ski activities in the same area. Of course, further study needs to be done to determine the demand for the corridor and the construction cost of a railroad. If the demand is too low and the cost is too high, then a secondary option may also be considered: high-capacity tourism bus.

Such buses would also be purposely built to have more doors for faster bordering and alighting, while also featuring more windows to maximize the experience of tourists.

Automatic operation, or at least semiautomatic operation, should be considered for both options. The current technology is already advanced enough to achieve at least semiautomatic operation of transit vehicles, and doing so would greatly reduce the operational coast. Furthermore, dynamic pricing may also be suitable for the Bear Lake Road corridor, and putting these measurements together would achieve more than applying a single strategy.

YELL is a large national park that spans across three states: Idaho, Montana and Wyoming. It has many roads in the park, and the distance between attractions is significant. Thus, public transit would have limited use in the park. Furthermore, YELL only opens half times of the year, which means that dynamic pricing, while would still be moderately useful, also has limited effectiveness. Extending the operational period of the park could certainly increase the capacity of the park, but this is done on the expanse of disrupting the wildlife in the park, which should not be acceptable. We also observed that parking tends to be a bottleneck in the park as well, even with a massive parking facility near the major attractions like the old faithful. Therefore, we suggest that constructing multi-level car parks could serve as a measurement to address parking issues. It has the advantage of not taking more land from the nature, while dramatically increasing the capacity of parking near major attraction. Multi-level car parks are not out of blue concepts, either. Hoover Dam, while not a national park, is a major tourist attraction located on the border of Arizona and Nevada. It is located in a canyon, which features limited space for parking. As a result, a multi-level parking facility of 459 spaces was built near the dam, greatly alleviating the parking issue in the Hoover Dam [6]. In general, multi-level car parks near major attractions would be extremely useful in national parks where public transit cannot be an effective mean to transport people and where parking is the dominant factor in determining the capacity of a park.

Conclusion

We have constructed a model based on historical data of total recreational visits per year to predict that there would be a rapid growth in the number of visitors in the near future. We then discussed in detail the current measurement taken by some NPSs to control the crowds, the timed entry reservation system, and how could the geographic location of a park impact the access to human resources and commercial services.

Furthermore, we offer suggestions on the alternatives and supplements of the current measurement to meet future tourism demand and preserve the natural environment within the park. We advocated for dynamic pricing to balance the number of visitors each month, which could also bring extra revenue to NPS to improve park infrastructure. The improvements could include the development of new railway lines within the park that may be purposely designed to be a tourist attraction itself, and the construction of multi-level car parks to increase the parking capacity near major attractions.

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