Integrated Transportation and User Capacity Research in Yosemite National Park

The Numbers Game

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The broad purpose of user capacity management in national parks is to identify the types and amounts of use that can be accommodated in a park, while desired resource and experiential conditions are maintained. Traffic management and transportation planning in national parks are increasingly recognized as inextricably linked with user capacity management. The purpose of this study was to develop a tool to integrate transportation and user capacity management in Yosemite National Park. The study consisted of three primary components. First, survey research was used to identify visitor-based standards of quality for crowding in Yosemite Valley. Second, regression modeling was used to estimate statistical relationships between inbound vehicle traffic at park entrance stations and visitor use levels at recreation sites in Yosemite Valley. Third, regression model estimates of visitor use at recreation sites in Yosemite Valley were simulated with computer models to estimate the extent of crowding that occurs in the valley as a result of different levels of inbound vehicle traffic at park entrance stations. Simulation results were compared with visitor-based standards to characterize the quality of visitor experiences in Yosemite Valley associated with different volumes of vehicle traffic entering the park. Thus, the results of this study provide an empirical basis for managing vehicle traffic entering the park in a manner that maintains the quality of visitors' experiences in Yosemite Valley. Further, the approach developed in this study can be adapted to other National Park System units to support integrated transportation planning and user capacity management systemwide.

National park visitation increased dramatically during the last half of the 20th century, from less than 50 million visits to the National Park System in 1940 to more than 300 million in 1999. And while national park visitation generally declined somewhat in the first several years of the 21st century, visitation was on the rise again in 2007, with more than 275 million visits to the National Park System. Thus, many units of the National Park System accommodate intensive levels of visitor use and this use can cause impacts to park resources and the quality of visitors' experiences (*1, 2*).

The National Park Service (NPS) has developed user capacity management plans and programs throughout the National Park System to address resource and experiential impacts associated with intensive park visitation. The primary purpose of user capacity management is to identify the types and amounts of visitor use that can be accommodated in a national park, while maintaining desired resource conditions and meaningful visitor experiences. The NPS approach to user capacity management can be characterized as indicator-based adaptive management, a core element that involves formulation of indicators and standards of quality (*3*). Indicators of quality are defined as measurable, manageable variables that reflect the essence or meaning of management objectives related to resource protection and the visitor experience. Standards of quality are defined as numerical expressions of desired future conditions of indicator variables. Monitoring of indicator variables is designed to detect and signal the need for management actions to ensure standards of quality are maintained over time (*4*).

Traffic operations and transportation planning are increasingly recognized as inextricably linked with user capacity management in national parks (*5*). In particular, decisions about how many, when, and by what means of conveyance visitors are allowed to access various locations throughout a national park are fundamental elements of both transportation planning and user capacity management. Yet, these decisions are often made with limited empirical information about the potential impacts of alternative traffic operations and transportation management strategies on park resources and visitors' experiences (*6*). For example, traffic management and related visitor access to recreation sites within a park are often guided solely by the physical capacity of a park's transportation infrastructure (e.g., number of parking spaces at trailheads).

The purpose of this study is to develop and demonstrate an approach to integrate transportation and user capacity management in national parks. To this end, the paper presents research conducted in Yosemite National Park to link automated traffic count data collected at park entrance stations with visitor use levels and associated crowding-related indicators of quality at popular recreation sites in Yosemite Valley. In doing so, this study provides the NPS with a basis for establishing numerical thresholds for inbound vehicle traffic at park entrances, beyond which visitors entering the park can be directed

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to visit areas of the park other than Yosemite Valley. Thus, the results of this study provide the NPS with an empirical basis for managing vehicle traffic entering the park in a manner that maintains the quality of visitors' experiences in Yosemite Valley. Further, the approach developed in this study can be adapted to other units throughout the National Park System to support integrated transportation planning and user capacity management systemwide.

METHODS

The conceptual and analytical framework for this study is illustrated in Figure 1, and corresponds to three interrelated research components. First, survey research was used to identify visitor-based standards of quality for crowding on trails and at attractions in Yosemite Valley. Second, regression modeling was used to estimate statistical relationships between inbound vehicle traffic at park entrance stations and visitor use levels at popular recreation sites in Yosemite Valley. Third, regression model estimates of visitor use at recreation sites in Yosemite Valley were simulated with computer models to estimate the extent of crowding that occurs in the valley as a result of different levels of inbound vehicle traffic at park entrance stations. Simulation modeling estimates of crowding were compared with visitor-based standards to characterize the quality of visitor experiences in Yosemite Valley associated with different volumes of vehicle traffic entering the park. The study area and methods used to conduct each component of the study are described in the following subsections.

Study Area

Yosemite National Park is located in the Sierra Nevada Mountains of California, approximately 150 mi east of San Francisco. In 2007, Yosemite ranked third among national parks in visitation, accommodating approximately 3.5 million visitors. The challenges associated with this intensive visitation to the park are exacerbated by the fact that much of the park's visitor use is concentrated in Yosemite Valley. The mile-wide, 7-mi-long Yosemite Valley comprises merely 4% of the park's total area, yet the valley accommodates 98% of all park visitation. Furthermore, visitor use peaks during the summer months, with 31% of all park visits occurring during July and August (*3*). Consequently, trails and attraction areas (e.g., the base of Yosemite Falls) are often overwhelmed by visitor use during periods of peak visitation. In visitor surveys conducted in Yosemite Valley during the summers of 1998 and 1999, respondents reported crowding on trails and at attractions as the factor that detracted most from their visit to the valley (*7*). Results of the surveys also suggest that visitors consider traffic congestion and difficulty finding parking as among the most significant management issues in Yosemite Valley.

To date, vehicle access to Yosemite Valley and related traffic operations management are conducted in a reactive manner. For example, during the busiest days in Yosemite National Park, vehicles are allowed to enter Yosemite Valley until the point when all parking spaces in the valley are occupied and additional vehicles are circling the roads in search of parking. Once these traffic conditions are reached, visitors are diverted to a roadway loop at the west end of Yosemite Valley, where they "orbit" the loop until other vehicles exit the valley. Thus, the decision to divert vehicles away from Yosemite Valley is made in "real time," once traffic conditions in the valley have become problematic. Further, the decision rule for implementing "the shunt" has been established without knowledge of how "filling" the valley's transportation infrastructure to its capacity affects the quality and character of visitors' experiences at recreation sites throughout the valley. This study is designed to support a more proactive, systematic, and integrated approach to managing transportation and user capacity in Yosemite National Park.

Visitor-Based Standards of Quality

Visitor surveys were conducted in Yosemite Valley during the summers of 1998 and 1999 to assist the NPS in formulating indicators and standards of quality for popular recreation sites, including Yosemite Falls, Bridalveil Fall, and the trail to Vernal Fall (Figure 2). Within the surveys, a visual approach was used to measure visitor-based standards of quality for crowding-related indicators of quality, including (*a*) people at one time (PAOT) at attractions (i.e., the base of Bridalveil Fall and Yosemite Falls) and (*b*) people per viewscape (PPV) on trails (*7, 8*). A series of computer-edited photographs was prepared for each study site showing a range of visitor use levels (e.g., Figure 3). Respondents were asked to rate the acceptability of each photograph on a scale that ranged from +4 ("very acceptable") to –4 ("very unacceptable") and included a neutral point of 0. In addition, respondents were asked to identify the photograph within each set that depicted the amount of use they would prefer to see and the maximum amount of use the NPS should allow before limiting use. Summary statistics computed from responses to these questions serve as potential standards of quality for crowding-related indicators in Yosemite Valley. These visitor-based standards are used in this study to evaluate the effects of varying levels of inbound vehicle traffic at park entrance stations on the quality of visitors' experiences in Yosemite Valley.

Inbound Vehicle Traffic and Recreation Site Use Counts

Automated vehicle traffic and trail counters were used to measure inbound vehicle traffic at park entrance stations and visitor use at

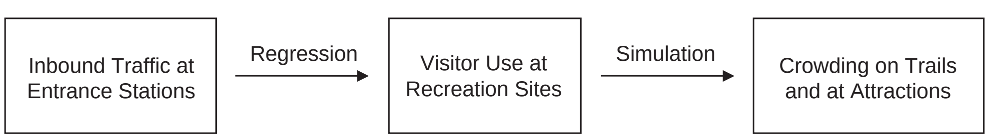

FIGURE 1 Conceptual and analytical framework for estimating crowding in Yosemite Valley via traffic counters at park entrances.

FIGURE 2 Map of Yosemite National Park.

recreation sites in Yosemite Valley, respectively. Regression analyses were conducted to statistically model relationships between inbound vehicle traffic and recreation site visitation. The methods used to measure and correlate inbound vehicle traffic at park entrance stations and visitor use counts in Yosemite Valley are described in the following subsections.

Inbound Vehicle Traffic Counts

Permanent inductive loop traffic counters are installed at each of the five park entrances into Yosemite National Park, and data from the counters are collected, analyzed, and summarized by the NPS Public Use Statistics office in Denver, CO. The park entrance stations include Arch Rock and Big Oak Flat, which provide access to the park from the west via Routes 140 and 120, respectively (Figure 2). The South entrance station provides visitors access to the park from the south on Route 41, and the Tioga Pass entrance station provides access to the park from the east on Route 120. The Hetch Hetchy entrance station is located on the northwest side of the park, and is accessed via the Hetch Hetchy Road off Route 120. The entrance station traffic counts recorded by the NPS permanent counters during the summer months of 2007 served as the primary source of traffic data for this study, with two exceptions. First, inbound traffic volumes at the Hetch Hetchy entrance station were excluded from this study because visitor arrivals at this entrance do not result in substantive daily visitation to recreation sites in Yosemite Valley. Second, the permanent counter located at the South entrance station was inoperable during the summer of 2007. Thus, traffic data used in this study include inbound vehicle traffic counts recorded by the NPS permanent counters at the Arch Rock, Big Oak Flat, and Tioga Pass entrance stations during June through August 2007.

To validate the permanent counter data, automated traffic tube counters were placed at park entrance stations from July 18 to

FIGURE 3 Computer-edited photographs of people per viewscape on the trail to Yosemite Falls.

July 30, 2007 to collect traffic volumes in 1-h increments. The two sets of traffic data were compared and were generally within 7% of one another, with tube counts generally slightly higher than those recorded with the NPS permanent counters.

Recreation Site Use Counts

Active infrared trail counters were used to measure daily visitor use at Yosemite Falls, Bridalveil Fall, and on the trail to Vernal Fall. In addition to counting visitor use on every day during the study period with mechanical counters, direct observations of visitor use were conducted at each counting location on six randomly selected days during the summer months of 2007. On each day direct observation counts were conducted, data were collected during four randomly selected hours between 7:00 a.m. and 7:00 p.m. The visitor use counts collected through direct observation by field staff were used to calibrate the mechanical counter data (*9–13*).

Correlation of Inbound Vehicle Traffic and Recreation Site Use

Regression models were estimated using hourly inbound vehicle traffic counts at park entrances as the primary independent variable and hourly recreation site visitation as the dependent variable. Other independent variables were included in the regression models to account for seasonality, time-of-day, and day-of-week effects (Table 1). Separate models were estimated for Yosemite Falls, Bridalveil Fall, and the trail to Vernal Fall. To estimate the regression models, hourly traffic and recreation site use counts were paired using a time delay or offset to account for the distance and travel time between the park entrance stations and the study sites in Yosemite Valley (Figure 2). For each recreation site, alternative regression models were estimated by using a range of delays or offsets to pair the vehicle traffic and site use data. The best-fitting models resulted from a 3-h offset for Yosemite Falls and the trail to Vernal Fall, and a 2-h offset for Bridalveil Fall. For example, inbound vehicle traffic during the 7:00 a.m. hour was paired with site visitation during the 10:00 a.m. hour to estimate models for Yosemite Falls and the trail to Vernal Fall. The regression models provide an empirical basis to estimate visitation at each of the three study sites in Yosemite Valley from inbound vehicle traffic at the park entrance stations. For example, the regression models were used to estimate daily visitor use at Yosemite Falls, Bridalveil Fall, and on the trail to Vernal Fall during the busiest, 7th busiest, and 50th busiest days of park visitation in 2007, as measured by inbound vehicle traffic at park entrance stations.

TABLE 1 Independent Variables Included in Regression Models Correlating Inbound Vehicle Traffic and Recreation Site Use

Variable Name	Description
Inbound vehicles	Hourly inbound vehicle traffic at park entrance stations
June	1 = June, 0 otherwise
July	1 = July, 0 otherwise
August	1 = August, 0 otherwise
5 a.m.	1 = 5:00 a.m.–6:00 a.m. hour, 0 otherwise
Morning	1 = 6:00 a.m.–11:00 a.m., 0 otherwise
Afternoon	1 = 12:00 p.m.–3:00 p.m., 0 otherwise
Midday	1 = 11:00 a.m.–2:00 p.m., 0 otherwise
Saturday	1 = Saturday, 0 otherwise
Inbound_5 a.m.	Interaction term: inbound vehicles ∗ 5 a.m.
Inbound_morning	Interaction term: inbound vehicles ∗ morning
Inbound_afternoon	Interaction term: inbound vehicles ∗ afternoon
Inbound_midday	Interaction term: inbound vehicles ∗ midday
Saturday_5 a.m.	Interaction term: Saturday ∗ 5 a.m.
Saturday_morning	Interaction term: Saturday ∗ morning
Saturday_afternoon	Interaction term: Saturday ∗ afternoon

Computer Simulation Modeling of Visitor Use

Computer simulation models of visitor use were developed for Yosemite Falls, Bridalveil Fall, and the trail to Vernal Fall. The computer models of visitor use provide a tool to estimate crowding on trails and at attractions associated with varying levels of recreation site visitation (*14, 15*). For example, the Yosemite Falls model is designed to provide estimates of PPV on the trail to Yosemite Falls and PAOT at the base of Yosemite Falls for user-specified levels of daily visitation to the site.

Two primary sources of data were needed to construct the visitor use models developed in this study. First, visitor surveys were conducted at each of the study sites in Yosemite Valley during the summer of 2007. The surveys were designed to collect site-specific information about visitors' group sizes, the modes of transportation visitors use to travel to the sites, and the length of time visitors spend hiking on trails and lingering at attractions. Second, visitor counts were conducted to measure average daily visitor use at each study site during the summer of 2007. These count data were used to specify simulated visitation levels to model baseline visitor use of the study sites.

The visitor survey and count data collected during the summer of 2007 were modeled by using discrete-event systems simulation software (*16*). The three site-specific models were structured to simulate visitor use and behavior of the study sites, including arriving at access points, hiking on trails, lingering at attraction sites, and exiting to the valley shuttle service or other mode of transportation. The models are also programmed to monitor PAOT at attractions and PPV on trails throughout the course of simulated visitor use days, and to compute the percentage of time during a simulated day PAOT and PPV standards are exceeded (*17*). The modeling interface is designed to allow the user to specify key simulation parameters, including daily site visitation and standards for PAOT at attractions and PPV on trails.

Integrated Transportation and User Capacity Analysis

Analyses were conducted to demonstrate how the components of this study can be integrated into a management tool capable of assessing the effects of alternative levels of vehicle traffic entering the park on crowding-related indicators of quality in Yosemite Valley. As stated, "traffic-site use" regression models were used to estimate visitor use of Yosemite Falls, Bridalveil Fall, and the trail to Vernal Fall on the busiest, 7th busiest, and 50th busiest days of park visitation during

2007, as measured by inbound vehicle traffic at park entrance stations. Regression model estimates of site visitation on the busiest, 7th busiest, and 50th busiest days during 2007 were simulated with the visitor use models of Yosemite Falls, Bridalveil Fall, and the trail to Vernal Fall. Simulation results provide estimates of the percentage of time visitor-based standards of quality for PAOT and PPV were exceeded on the busiest, 7th busiest, and 50th busiest days of 2007.

A second set of analyses was conducted to illustrate how the information collected in this study can be used to specify numerical thresholds for inbound vehicle traffic at park entrance stations, beyond which visitor-based standards of quality for crowding are violated at recreation sites in Yosemite Valley. First, a series of simulations was conducted to estimate the amount of daily visitor use that can be accommodated at Yosemite Falls without exceeding visitor-based standards for PAOT at the base of the falls more than 10% of the time during the day—referred to as daily user capacity of Yosemite Falls. Second, the daily user capacity estimates generated with the computer model of visitor use at Yosemite Falls were used in conjunction with the "traffic-site use" regression model for Yosemite Falls to "solve" for the corresponding volume of inbound vehicle traffic at park entrance stations. The results of these analyses constitute estimates of the maximum number of vehicles that can be accommodated in Yosemite National Park while maintaining desired experiential conditions at Yosemite Falls.

RESULTS

Visitor-Based Standards of Quality

Visitor-based standards of quality derived from responses to surveys administered in Yosemite Valley during the summers of 1998 and 1999 are presented in Tables 2 and 3. "Acceptability" standards of quality were derived by plotting average acceptability ratings for each of the visitor use levels shown in the six photographs for each study site. The PAOT and PVV standards of quality shown in the tables are points at which average acceptability ratings cross the "0" or neutral point on the acceptability scale (i.e., fall out of the "acceptable" range and into the "unacceptable" range). "Preference" and "management action" standards of quality were derived by calculating the average number of people in the photographs selected by visitors in response to the questions described in the methods section. For example, results for the Trail to Yosemite Falls reported in Table 2 are based on visitors' average acceptability ratings and responses to the "preference" and "management action" questions associated with the photographs depicted in Figure 3.

TABLE 2 Visitor-Based Standards of Quality for PPV on Trails in Yosemite Valley

Standard of Quality	Trail to Vernal Fall	Trail to Yosemite Falls	Trail to Bridalveil Fall
Preference	11	18	7
Acceptability	26	40	18
Management action	30	46	20

NOTE: Standards are for PPV on a 50-m section of the trail.

TABLE 3 Visitor-Based Standards of Quality for PAOT at Attractions in Yosemite Valley

Standard of Quality	Base of Yosemite Falls	Base of Bridalveil Fall
Preference	43	8
Acceptability	92	19
Management action	100	19

NOTE: Standards are for PAOT in the viewing area at the base of the falls.

Correlation of Inbound Vehicle Traffic and Recreation Site Use

Table 4 presents the results of regression analyses conducted to correlate inbound vehicle traffic at park entrance stations and visitor use at Yosemite Falls, Bridalveil Fall, and the trail to Vernal Fall (refer to Table 1 for a description of independent variables included

TABLE 4 Regression Model Coefficient Estimates, by Location

	Trail to Vernal Fall	Yosemite Falls	Bridalveil Fall
Constant	21.051 (21.038)	–93.431*** (9.513)	–120.740*** (7.211)
Inbound vehicles	0.459*** (0.071)	0.701*** (0.034)	0.937*** (0.027)
June	45.937*** (3.861)	267.178*** (8.543)	148.166*** (5.080)
July	41.733*** (4.950)	193.218*** (8.507)	89.242*** (5.035)
August	36.662*** (4.403)	31.128*** (8.279)	29.894*** (5.224)
5 a.m.	–27.549 (23.261)	—	—
Morning	–3.284 (21.306)	—	—
Afternoon	49.035** (24.548)	—	—
Midday	—	93.534*** (8.276)	114.963*** (14.938)
Saturday	137.178*** (11.421)	—	—
Inbound_5 a.m.	–0.640 (2.002)	—	—
Inbound_morning	0.071 (0.074)	—	—
Inbound_afternoon	–0.158** (0.077)	—	—
Inbound_midday	—	—	0.261*** (0.040)
Saturday_5 a.m.	–95.341*** (21.172)	—	—
Saturday_morning	–76.013*** (13.104)	—	—
Saturday_afternoon	–38.791*** (14.150)	—	—
Model *R*-square	0.749	0.720	0.811

NOTE: Standard errors are in parentheses. — indicates regression coefficients for variables not estimated.
*0.10 > *p*-value ≥ 0.05; **0.05 > *p*-value ≥ 0.01; ****p*-value < 0.01.

TABLE 5 Regression Model Estimates of Daily Visitor Use at Recreation Sites in Yosemite Valley on Busiest, 7th Busiest, and 50th Busiest Days of 2007

Location	Busiest Day (4,154 vehicles)[a]	7th Busiest Day (3,418 vehicles)[a]	50th Busiest Day (2,736 vehicles)[a]
Trail to Vernal Fall[b]	2,377	2,108	1,374
Yosemite Falls[b]	3,988	3,130	2,671
Bridalveil Fall[b]	3,508	2,634	2,140

[a]Sum of inbound vehicle traffic from Arch Rock, Tioga Pass, and Big Oak Flat entrances, 7 a.m. to 2 p.m. for Vernal Fall and Yosemite Falls models, 8 a.m. to 3 p.m. for Bridalveil Fall model.
[b]Estimated daily site visitation, 10 a.m. to 5 p.m.

in the regression models). All coefficient estimates in the Yosemite Falls and Bridalveil Fall regression models, and most coefficient estimates in the model for the trail to Vernal Fall, are statistically significant at an alpha level of 0.05 or better. Model R-squares range from 0.720 for the Yosemite Falls regression model, to 0.811 for the Bridalveil Fall model. These results suggest that there are robust statistical relationships between inbound vehicle traffic volumes at park entrance stations and daily visitor use at Yosemite Falls, Bridalveil Fall, and on the trail to Vernal Fall.

The regression models reported in Table 4 were used to estimate daily visitor use at Yosemite Falls, Bridalveil Fall, and the trail to Vernal Fall based on inbound vehicle traffic counts at the park entrance stations on the busiest, 7th busiest, and 50th busiest days of 2007. Results of these analyses are presented in Table 4.

Simulation of Visitor Use Levels—Busiest, 7th Busiest, 50th Busiest Days of 2007

As stated, regression model estimates of site visitation on the busiest, 7th busiest, and 50th busiest days of 2007 (see Table 5) were simulated with the visitor use models of Yosemite Falls, Bridalveil Fall, and the trail to Vernal Fall. Results of these simulations are reported in Table 6. The table reports the percentage of time visitor-based "management action" standards of quality are violated for each of the three modeling scenarios. The "management action" standards represent the maximum PPV on trails and PAOT at attractions visitors think the National Park Service should allow before limiting use. The results suggest that even during peak visitation periods in 2007, visitor-based "management action" standards for crowding are rarely exceeded on the trail to Vernal Fall and at Yosemite Falls. In contrast, results of the simulations at Bridalveil Fall suggest that crowding is a significant user capacity management issue, particularly in the viewing platform area at the base of the fall. It should be noted that results of simulations vary according to the standards specified for analysis. For example, results of simulations not presented in Table 6 suggest that on the 50th busiest day in 2007, visitor-based "preference" standards (i.e., the maximum amount of PPV on trails and PAOT at attractions visitors would prefer to see) are exceeded 13.3% of the time on the trail to Vernal Fall, 46.3% of the time at the base of Yosemite Falls, and more than three-quarters (77.4%) of the time at the base of Bridalveil Fall. Thus, management judgments about desired conditions for visitor experiences (i.e., standards of quality) are a necessary precursor to fully implementing the user capacity methods developed in this study.

Estimating Inbound Vehicle Traffic Capacities

Table 7 reports estimates of the maximum amount of inbound vehicle traffic Yosemite National Park can accommodate per hour and per day, without violating visitor-based standards of quality for PAOT at the base Yosemite Falls more than 10% of the time during the day. The estimates of inbound vehicle traffic capacities presented in Table 7 were generated through a series of simulation and regression modeling steps described in the methods section. The results reported in Table 7 suggest that parkwide inbound vehicle traffic would need to be reduced by about 60% from the busiest day in 2007 and by about 50% from the 7th busiest day in 2007 to manage for visitors' "preference" standard at Yosemite Falls. Managing for visitors' "acceptability" standard would require inbound vehicle traffic to be reduced by about 15% from that on the busiest day in 2007 and could

TABLE 6 Percentage of Time Visitor-Based "Management Action" Standards are Exceeded on Busiest, 7th Busiest, and 50th Busiest Days of 2007[a]

Simulation Scenario	Trail to Vernal Fall (%)	Trail to Yosemite Falls (%)	Base of Yosemite Falls (%)	Trail to Bridalveil Fall (%)	Base of Bridalveil Fall (%)
Busiest day	1.2 (±0.1)	0.1 (±0.0)	10.1 (±0.7)	28.2 (±0.3)	72.3 (±0.3)
7th busiest day	0.7 (±0.1)	0.0 (±0.0)	0.9 (±0.2)	20.5 (±0.3)	66.4 (±0.4)
50th busiest day	0.1 (±0.0)	0.0 (±0.0)	0.1 (±0.0)	10.2 (±0.2)	59.4 (±0.5)

[a]Estimated for the hours of 10 a.m. to 5 p.m.
[b]Numbers in parentheses represent 95% confidence intervals for estimated percentages of time.

TABLE 7 Estimated Parkwide Inbound Traffic Capacities for Visitor-Based Crowding Standards at Base of Yosemite Falls

	Estimated Hourly Inbound Traffic Capacities[a]		
Hour of Day	Preference	Acceptability	Management Action
7:00 a.m.	182	296	316
8:00 a.m.	155	397	439
9:00 a.m.	156	401	443
10:00 a.m.	189	474	523
11:00 a.m.	313	585	632
12:00 p.m.	284	522	563
1:00 p.m.	260	468	504
2:00 p.m.	231	405	435
Total	1,771	3,550	3,857

[a]Sum of inbound vehicle traffic from Arch Rock, Tioga Pass, and Big Oak Flat entrances.

be increased by just over 5% from that of the 7th busiest day in 2007. If inbound vehicle traffic were managed to maintain visitors' "management action" standard, inbound traffic would need to be reduced by less than 10% of that on the busiest day in 2007 and could be increased by about 15% from traffic levels on the 7th busiest day in 2007. This discussion implies that the capacities reported in Table 7 would be used to define a point at which vehicle arrivals into the park would be limited. An alternative approach would be to use the figures in the table to identify thresholds of inbound vehicle traffic, by time of day, beyond which visitors would be directed to visit areas of the park other than Yosemite Valley, or at least Yosemite Falls.

DISCUSSION OF METHODOLOGY

The methodology developed in this study to support integrated transportation and user capacity management in Yosemite National Park has at least four important characteristics. First, the approach used in this study is grounded in the logic and framework of indicator-based, adaptive management, which is the state of art and practice in natural resource management and science. Second, the approach is proactive, in that it uses predictive modeling to support management decisions based on desired park conditions, rather than in reaction to problems on the ground. Third, the method developed in this study can be characterized as numerical, in that it provides an empirical basis for quantitative standards for crowding-related indicators of quality and numerical thresholds for inbound traffic volumes at park entrance stations. The quantitative nature of the management tool developed in this study is significant in light of a recent court ruling on the NPS Merced River Plan directing the NPS to develop a numerical approach to user capacity management in Yosemite National Park. Fourth, the conceptual, methodological, and managerial framework developed in this study is adaptable to other units of the National Park System to support integrated transportation and user capacity management systemwide.

While the research conducted in this study has the potential to support proactive, indicator-based management of transportation and user capacity in Yosemite National Park, the study has limitations. First, the inbound vehicle traffic data used in this study do not include data from the South entrance station, which in recent years has been the busiest point of entry into the park. However, it is possible to use historical data to estimate the proportion of all park visitation that enters Yosemite National Park at the South entrance station and adjust inbound traffic capacities estimated in this study accordingly. Second, visitor-based standards of quality for crowding-related indicators used in this study were derived from studies conducted in 1998 and 1999; thus these data may be considered somewhat dated. This issue is particularly pronounced in the case of visitor-based standards for PAOT at the base of Yosemite Falls, as this site has been significantly redesigned since the visitor survey was conducted in 1998. As part of the redesign of the recreation site at Yosemite Falls, the size of the viewing area at the base of the falls was increased significantly. Thus, estimated site capacities for Yosemite Falls and corresponding inbound vehicle traffic capacities presented in the results section could underestimate the true capacities. Third, while the models presented in this study produce estimates that are statistically robust and have a high degree of face validity, additional research is warranted to collect PPV, PAOT, and site use data that could serve as the basis for validating the computer models' predictive accuracy. Fourth, the modeling conducted in this study does not explicitly account for internal trips within the park (e.g., trips that originate from overnight accommodations within the park, rather than at entrance stations). However, the study models' estimates of recreation site use and capacities do account for the effects of internal trips on site use and capacities. Specifically, the regression models correlating inbound vehicle traffic at entrance stations and recreation site use estimate the amount of use that can be expected at study sites, inclusive of internal trips, associated with varying levels of entrance station traffic. Thus, a diary survey or other method to study internal trips within the park is not necessary to estimate statistical relationships between inbound vehicle traffic at entrance stations and recreation site use. However, information about visitors' travel patterns within the park could be helpful in estimating the effects of limiting access to Yosemite Valley on crowding conditions in other areas of the park. Finally, the research conducted in this study can be characterized as "Yosemite Valley-centric." That is, capacities for inbound vehicle traffic at park entrance stations are estimated without accounting for the potential impacts to visitors' experiences in other areas of the park associated with diverting use away from Yosemite Valley when inbound traffic capacities are reached. However, the conceptual and analytical framework developed in this study could be extended to other areas of the park to support a parkwide approach. Despite the study limitations noted, the methods and results presented here provide the NPS with a systematic approach to monitor and proactively manage the effects of traffic management on visitors' experiences in Yosemite National Park. Additional work is ongoing to test the adaptability of the approach to other national park contexts.

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REFERENCES

1. Leung, Y.-F., and J. Marion. Recreation Impacts and Management in Wilderness: A State-of-Knowledge Review. In *Wilderness Science in a Time of Change, Volume 5: Wilderness Ecosystems, Threats, and Management* (D. N. Cole, S. F. McCool, W. T. Borrie, and J. O'Loughlin, compilers), Forest Service, U.S. Department of Agriculture, Rocky Mountain Research Station, Ogden, Utah, 2000, pp. 23–48.
2. Hendee, J., and C. Dawson. *Wilderness Management: Stewardship and Protection of Resources and Values*, 3rd ed. Fulcrum Publishing, Golden, Colo., 2002.
3. *VERP: The Visitor Experience and Resource Protection Framework: A Handbook for Planners and Managers.* National Park Service Technical Report, U.S. Department of the Interior, 1997.
4. Bennetts, R., J. Gross, K. Cahill, C. McIntyre, B. Bingham, A. Hubbard, L. Cameron, and S. Carter. Linking Monitoring to Management and Planning: Assessment Points as a Generalized Approach. *George Wright Forum*, Vol. 24, No. 2, 2007, pp. 59–77.
5. Daigle, J. Transportation Research Needs in National Parks: A Summary and Exploration of Future Trends. *George Wright Forum*, Vol. 25, No. 1, 2008, pp. 57–64.
6. McCool, S., and D. Cole. Thinking and Acting Regionally: Toward Better Decisions About Appropriate Conditions, Standards, and Restrictions on Recreation Use. *George Wright Forum*, Vol. 18, No. 3, 2001, pp. 85–98.
7. Manning, R., W. Valliere, B. Wang, S. Lawson, and P. Newman. Estimating Day Use Social Carrying Capacity in Yosemite National Park. *Leisure*, Vol. 27, No. 1–2, 2003, pp. 77–102.
8. Manning, R. *Parks and Carrying Capacity.* Island Press, Washington, D.C., 2007.
9. Bates, M., G. Wallace, and J. Vaske. *Estimating Visitor Use in Rocky Mountain National Park.* Colorado State University, Fort Collins, 2007.
10. Gracias-Longares, M. *Study of Spatial Patterns of Visitors Using Mechanical Counters, GPS, and GIS Technology in the Slough Creek Subregion of Yellowstone National Park.* MS thesis. University of Montana, Bozeman, 2005.
11. Titre, J., M. Bates, and R. Gumina. *Boulder Open Space and Mountain Parks Use Estimation and Visitor Survey Study for the Chautauqua Area.* Final Report for Boulder Open Space and Mountain Parks, Boulder, Colo., 2004.
12. Vaske, J., and M. Donnelly. *Estimating Visitor Use at Boulder Open Space and Mountain Parks: Summer 2004–2006 Comparisons.* Colorado State University, Fort Collins, 2007.
13. Watson, A., D. Cole, D. Turner, and P. Reynolds. *Wilderness Recreation Use Estimation: A Handbook of Methods and Systems.* U.S. Forest Service (General Technical Report RMRS-GTR-56), Ogden, Utah, 2000.
14. Lawson, S. Computer Simulation as a Tool for Planning and Management of Visitor Use in Protected Natural Areas. *Journal of Sustainable Tourism*, Vol. 14, No. 6, 2006, pp. 600–617.
15. Lawson, S., R. Manning, W. Valliere, and B. Wang. Proactive Monitoring and Adaptive Management of Social Carrying Capacity in Arches National Park: An Application of Computer Simulation Modeling. *Journal of Environmental Management*, Vol. 68, 2003, pp. 305–313.
16. Diamond, B., S. Lamperti, D. Krahl, and A. Nastasi. *Extend, Version 6.0.* Imagine That Inc., San Jose, Calif., 2002.
17. Kiser, B., S. Lawson, and R. Itami. Assessing the Reliability of Computer Simulation for Modeling Low-Use Visitor Landscapes. In *Monitoring, Simulation, and Management of Visitor Landscapes* (H. Gimblett, H. Skov-Petersen, and A. Muhar, eds.), University of Arizona Press, Tucson, 2008.

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