Rethinking tourism sustainability: integrating data science for carrying capacity and adaptive policies

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Abstract

The research on tourism carrying capacity seeks to comprehend the adverse effects exerted by overwhelming tourist pressure on a destination's resources. The primary goal is to foster the development of effective response strategies to support more sustainable tourism. However, the implementation of these strategies often faces challenges, leading to the frequent imposition of difficult-to-enforce limits on tourist flows. This necessitates the exploration of alternative and more adaptable approaches. This study aims to underscore the significance of a data-driven approach in identifying crucial pressure points. These points, referred to as bottlenecks, are systematically evaluated through the segmentation of the tourism subsystem and the analysis of various visitor types. This method provides a more precise and detailed understanding of tourist flows, guiding the formulation of intervention strategies prioritizing adaptability and optimization of tourist resources over rigid flow limitations. Three case studies are examined within their systemic context, utilizing a carrying capacity scenario simulator and a predefined set of indicators. The results highlight the effectiveness of adopting soft policies to address excessive tourism pressure, without the need for stringent measures and significant infrastructure investments.

Contemporary tourism scenarios increasingly denote an intrinsic complexity of dynamics layered in contexts that are often not exclusively tourism-oriented, generating significant impacts on the surrounding environment and the perception of it, both by visitors and residents, often with a negative connotation. Simultaneously, the concept of overtourism has been widely debated in recent years, accordingly defining “a destination's situation where tourism excessively influences the perceived quality of life of citizens and/or quality of visitors' experiences in a negative way” (UNWTO, 2018a). Among the most observed and evident phenomena often attested are congestion of cities, gentrification, overcrowding of seaside destinations, and some UNESCO heritage sites (Camatti et al., 2020). However, it is necessary to specify that overtourism is not a purely excessive crowding of places, but rather a consistent and constant presence of tourists that generates pressure on local residential activities, services, and facilities (Butler, 2018).

Therefore, this phenomenon brings out a misrepresentation regarding the qualitative perception of visitation and particularly of tourist facilities, an unfavorable condition present in several global destinations. Concerning this, the UNWTO has asked “*How many tourists are too many?*” and numerous researchers have tried to answer this question by analyzing the negative evidence of the exponential growth of the phenomenon. The complexity of the issue has generated a prolific base of contextual and often indicator-specific studies (Capocchi et al., 2019), such as quality of life (Veiga et al, 2018), heritage (Adie and Falk, 2021), natural and socio-cultural resources (Mihalic & Kušcer, 2021), place attachment (Gössling et al, 2020) and others who in related contexts have shown that overcrowding reduces visitor satisfaction and loyalty (Luque-Gil et al., 2018). The negative consequences examined within the destinations dynamics thus argue for the urgency of finding increasingly systemic solutions, given the high degree of criticality that many of them show, especially in seasonal contexts and/or small geographic areas.

An important set of researched solutions draws on studies of tourism carrying capacity (TCC). The term “capacity” suggests the condition of containment-hospitality of a maximum quantity in a specific space or area. This concept has origins in ecological and environmental science studies, representing the “maximum number, density, or biomass of a population that a specific area can support” (Hartvigsen, 2017).

This concept has shown potential for adaptation to other domains, leading to its translation and repurposing also within the tourism sector. Therefore, TCC (Tourism Carrying Capacity) denotes the maximum capacity of visitors that a particular destination can accommodate.

However, the definitions differ depending on the approaches of scholars and reference contexts, in particular changing in the identification of the limits. For example, socio-economic TCC is defined as the maximum number of visitors that can visit the city without compromising its performance; differently, in urban areas, TCC has been defined as the ability of a destination to absorb and manage tourism activities without degradation in the tourism and economic sector (García-Buades et al., 2022). Coccossis and Mexa (2004) consider TCC as the limit over which the social and economic functions of the considered area are damaged - resulting in the degradation of the quality of life of the host population. For other academics, TCC is the interval within which the process of sustainable tourism development occurs. The upper limit of this interval is the intensive development of the tourist resource, while the lower limit is the tourism development option that takes shape more moderately: it is precisely between these two limits that the TCC approach - considered as the very concretization of the concept of sustainable tourism, finds its place (Michelangeli et al. 2006).

The UNWTO definition of TCC from 1981, as the "maximum number of people who can visit a tourist destination at the same time without causing destruction of the physical, economic, socio-cultural environment, and an unacceptable decrease in the quality of visitor satisfaction," underscores the need to not only consider the number of tourists, but also its impact on the overall visitor experience. When the quality of the visitor experience is compromised, it can irreversibly hinder the balanced and long-term development of the destination. Consequently, tourist capacity also involves those levels beyond which tourist flows decline due to perceived reductions in capacities by the tourists themselves. When a destination fails to satisfy and attract visitors, they seek alternative destinations, as noted by O'Reilly in 1986.

Generally, TCC is very important for planning and management that aims to identify the acceptable level of intensity of changes caused by tourists in a specific area, while its application indicates the ideal conditions for development. Bertocchi et al. (2020) speak of “a “multidimensional trade-off” encompassing heterogeneous groups of physical, social, and economic effects induced by tourism, each of which is characterized by its characteristics and consequences”. Considerations arising from the interrelation of these dimensions of a destination's sustainability have prompted studies of carrying capacity and overtourism to be associated with the concept of “excess,” often attempting to determine a maximum number of visitors. This concept allows for maintaining the balance between both the physical-social environment and the quality of the experience for the visitor, conceiving a dynamic management solution used to improve tourist visitation, implementing sustainable management, and coping with the issue of overtourism (Coccossis and Mexa, 2004).

However, many carrying capacity studies have been challenged for being too focused on finding a threshold number, or for being based on the analysis of industry-specific technical indicators (Abernethy, 2001). On this basis, many destinations have operated through "hard politics" that, for example, place limits on destination entry, restrict access zones, and time limits on dwell time (Eckert et al., 2019). However, each regulation must be addressed in a specific manner (Capocchi et al 2019): applying too strict and/or overgeneralized limits to the whole destination has the potential to penalize areas that are not directly affected and fail to solve congestion points. Decreeing the difficulty and failure of policies underscores the responsibility of administrations to implement suitable policies for the system. Each destination faces unique challenges related to the TCC, and therefore limits should be calibrated and tailored to specific local realities (Mowforth and Munt, 2003). There are no "one-size-fits-all" solutions to solve the problems (Koens et al., 2018) instead on the contrary, each destination requires a more detailed and specific analysis of tourism subsystems to avoid generic and sketchy restriction policies on the entire destination. Limitations should therefore be based on targeted policies, detailed analysis, and concrete data at the subsystem level, which is the reason that drives the search for new, more consistent approaches to specific problems (Coccossis and Mexa, 2004). Otherwise, excess flow absorption strategies based on infrastructure investments carry high financial risks and new overloads. Needing medium to long timeframes for their completion, they risk misalignment with flow dynamics developments and subsequent underutilization.

This research focuses on studying TCC and implementing policies to reduce excessive tourism pressure. We show how the problems of tourist overload can be re-addressed through the definition of soft strategies that do not involve the introduction of stringent limits on the flows of a destination as a whole or new investments in infrastructure. This can be achieved by dismantling the tangle of tourist flows and their excess by operating at the level of the tourist subsystems of which a destination is composed. Being able to develop targeted and less generic interventions leads to the definition of solutions and interventions adaptable to the specific and different needs of a particular tourist destination under consideration. Working on the subsystem level improves sustainable innovation in the tourism industry, which conversely helps increase employment opportunities and the economy. Moreover, this management approach aligns with the Sustainable Development Goals (SDGs), particularly the 8th (decent work and economic growth), the 9th (industry, innovation, and infrastructure), and the 11th (sustainable cities and communities).

The term "system" denotes a collection of interconnected elements forming a unified functional structure (Weaver & Oppermann, 2000). Originating from von Bertalanffy's general systems theory, this concept seeks to unravel complexity by dissecting elements and comprehending their interconnections (Leiper, 2000). Employing a systems approach enables a holistic understanding of destinations and a clear representation of various factors along with their relationships (Pearce, D. G., 2014). As Leiper (1979) observes, tourism defined in a systems framework would allow each of its fundamental aspects to be identified, facilitating multidisciplinary studies focused on specific aspects of tourism. Key elements within this system include tourists, geographic components, and an industrial component where crucial factors such as accommodations, attractions, and various services play a critical role in satisfying tourists' needs and desires (Leiper, 1979).

Barrado Timón (2004) provides a geographical perspective, depicting a destination as a system overlapping various sectoral and territorial systems. It is crucial to note that not all territory occupied by a destination is exclusively dedicated to tourism; other functions coexist. The diverse elements of the system converge within the destination, particularly in areas designed for reception, infrastructure, services, and resources utilized by tourists. This approach acknowledges the multifaceted nature of tourism and the intricate interplay between its components within a destination.

Costa-Canestrelli (1991) introduced a model that takes a systems approach to understanding tourism, addressing, in particular, the challenges posed by excessive tourist pressure on key subsystems, including accommodation, catering, mobility, and attractions. This model offers a comprehensive analytical framework for tourism carrying capacity (TCC), interpreting it as tolerable tourism stress for each subsystem as a whole. Unlike a singular indicator, the model supports segmentation into subsystems, evaluating maximum physical-functional stress while optimizing consumption coefficients, resource use, and revenue maximization.

The analysis identifies congestion points as potential sources of negative externalities, which contribute to a condition of overtourism. By establishing a limit to tourist pressure and identifying “bottlenecks” and their interconnection with other subsystems, the model aims to formulate concrete strategies to promote a more sustainable tourism model based on the adaptability of resources. However, its application has been rather limited, mainly limited to the determination of threshold values applied uniformly to the entire tourism system and to the tourist destination (Costa & Canestrelli, 1991, Van der Borg et al., 1996; Coccossis and Mexa, 2004; Bertocchi, 2020;

Camatti, 2020). Moreover, as this study aims to demonstrate, the model can represent a valuable tool for simulating "softer" interventions and policies aimed at the fundamental variables and coefficients within each tourism subsystem.

These solutions aim to avoid large infrastructure investments and take a more flexible and tailored form, operating as needed on physical capacity, behavior, or the number and type of users using certain subsystems.

According to Oh et al. (2005) and Zelenka and Kacetl (2014), TCC does not refer to the number of tourists to the destination but also refers to tourists' behavioral patterns and other factors that vary according to the geographical context. Therefore, by analyzing the typology of users, their behavior through the rate of use, and the constraints defined by the physical limits of the subsystems, it was possible to establish the boundary within which it is possible to elaborate the variation necessary to create scenarios, tensing every possible level of susceptibility of the subsystems.

The calculation of the tourism carrying capacity through a linear programming method as set by Costa and Canestrelli (1991) is based on a computational model of the TCC which seeks to maximize the daily profit within the maximum stress thresholds that the subsystems can withstand, without being overcome by the entire system. This requires the following steps: 1) identify the tourism subsystems of a destination (*Table 1*), especially regarding tourism facilities and services; 2) classify the type of users who often utilize those subsystems (*Table 2*); 3) determine the level of usage of these subsystems by user profile; 4) proceed with the analysis to maximize the revenue of the destination through understanding the daily expenditure per each profile.

If the maximum stress thresholds of the system were evaluated, the outcomes would be associated with an imposition of a maximum limit on the number of visitors, broken down by tourist type, applied to the entire tourist destination as a whole. Our study aims to intervene in phase 3 through simulations of the change of ecosystem coefficients relating to the rates of use of tourist resources rather than limited changes in the stress capacity of each subsystem. The policy associated with these results is the development of soft intervention policies on the tourist sector (i.e. how they use ecosystem resources), containing regulations on tourist flows and absorption capacity at the level of individual tourism subsystems.

Table 1. *Five crucial tourism subsystems have been identified as those that can create destination-level constraints and bring significant changes in economic spillovers.*

Accommodation – Hotels	This category may include small hotels, *hotels garnis*, boutique hotels.
Accommodation – Extra-Hotels	This category may include Airbnb rentals, B&Bs, campsites, second homes, apartments.
Food & Beverage	It indicates the total number of restaurants, bars, and pubs sits - focusing only on places where it is possible to sit down to consume a meal.
Mobility	It is intended as a whole system and consequently divided into two subsystems: *parking* places in the destination and the main gateways of the city and the capacity of the main public *transportation* lines in the destination.
Attraction	It is the main attraction of the destination, namely one of the main reasons that determine the motivation to visit a destination and the main point of interest and visit.

Table 2. *Profiling has identified three user profiles able to yield net benefits for the destination.*

H	Hotel tourists
NH	Extra-hotel tourists
E	Day visitors

The level of usage (below as *usage rate* (UR)) is fundamental to interpret the impacts of the profiles on the destination, having each of them a different behavior in using the services expressed with the subsystems. This has required the administration of stakeholder surveys from which it is possible to trace profiled responses. Each destination provided n=100 correctly completed stakeholder surveys. The main survey items were related to the profile of tourists, the form of accommodation used, the accessibility of the destination, and the main attraction. Some questions relate to the *average daily expenditure*, the evaluation of the crowdedness, the behavior of the visitor profile, and *tourism flows*.

Building upon the framework introduced by Canestrelli and Costa (1991), the computation of the TCC is conceptualized as an optimization challenge geared towards maximizing the benefits derived from tourism for a destination. These benefits are quantified in terms of monetary revenues, determined by the expenditures of tourists across various types of visits (H, NH, and E). The model is designed to operate within specific constraints, ensuring that the increasing number of visitors does not surpass the maximum stress levels that each tourist subsystem within a destination can endure.

The model encompasses a minimum of four subsystems, namely those presented in *Table 1,* each of whom plays a vital role in contributing to the overall tourism experience. The optimization objective is to establish a harmonious equilibrium wherein each subsystem can effectively operate without exceeding its predetermined threshold values. In essence, the entire tourism system must operate at its peak efficiency, guaranteeing that each subsystem can function concurrently without surpassing its capacity limitations.

The model seeks to achieve this objective while abiding by constraints associated with the stress thresholds of each tourism subsystem. This comprehensive approach ensures that the destination maximizes its economic gains from tourism while also safeguarding the functionality of its crucial tourist subsystems. This optimization challenge can be articulated as a linear programming problem, where the objective is to maximize the overall benefits derived from tourism given a set of constraints. Formally it can be expressed by the following problem of maximization of the objective (1):

$max\ ({}_x cx)$ (1) subject to the constraints:

$$Bx \leq d\ ,x \geq 0$$

where c_i are the coefficients of the objective function, $b_{i,j}$ the technical coefficients, and d_j the second side coefficients.

The extended form of the problem is represented as:

$maxc_1THmax + c_2NTH + c_3E$ subject to:

$$\begin{aligned}
&TH \leq d_1 \\
&TNH \leq d_2 \\
&b_{3,1}TH + b_{3,2}NTH + b_{3,3}E \leq d_3 \\
&b_{5,1}TH + b_{5,2}NTH + b_{5,3}E \leq d_5 \\
&b_{6,1}TH + b_{6,2}NTH + b_{6,3}E \leq d_6 \\
&b_{7,1}TH + b_{7,2}NTH + b_{7,3}E \leq d_7 \\
&TH, NTH, E \geq 0
\end{aligned}$$

In this formulation, TH, NTH, and E represent different user types, specifically hotel tourists, non-traditional hotel tourists, and day visitors. The objective is to determine the optimal number of each user type to maximize the objective function, taking into account their respective budget levels c_1 , c_2 , c_3 , coefficients of usage rate of each resources $b_{i,j}, and\ the\ constraints\ d_j$ associated with each tourism subsystem.

Further operationalizations are pursued to conduct more simulations and/or solve the susceptibility grades of the subsystems, providing other scenarios as recommendations for future management implications. The simulations describe a range of possible scenarios and not a static reality, implying that working on other modifications may lead to different interpretations. The goal is resolving the critical subsystems within the indicated range by ensuring a heterogeneous presence of all three profiles. This also considers the limited economic impact the *day visitors* (E) have, where, instead, their behavior and use of the subsystems have major repercussions on the whole system.

The analysis has been conducted with data (*Table 3*) and survey responses (*Table 4*) collected between 2021 and 2023.

Table 3. *Dataset and related notes.*

	Notes
Tourism flows	Daily number of tourists flows. Data were provided by two out of three destinations on an annual basis, thus a daily average including high and low season. The study does not take a comparative approach, and the model makes itself suitable for choosing specific periods. For instance, the third destination chose to focus on the peak season (summer months) by providing pertinent data.
Accommodation – Hotel and Extra-Hotel	It indicates the number of beds relative to hotel and extra-hotel facilities.
Food & Beverage	It has been evaluated with the total amount of seats (as indicated in *Table 1*) and the service(s) provided at lunchtime only, in two shifts.
Mobility	*Parking*: number of parking places in the destination and in the main gateways of the city. *Transportation*: considered as the number of people the main bus, tram, and metro lines in the pilot area can transport daily.

Attraction	It has been established as the indicator of capacity which shows the maximum number of daily people set by visitor limits or security reasons.
Daily Expenditure	It is intended as the average daily expenditure for user profile.

Table 4. *Optimal samples requested for the surveys.*

Surveys	Note
Stakeholder	It needs to be evaluated case by case. The optimal sample requested (>50) is 5% of hotel stakeholders, 5% of cultural stakeholders, and 5% of restaurant stakeholders.

Table 5*. Usage rates and related notes.*

	Usage Rate	Notes
Accommodation – Hotel and Extra-Hotel	0 – 1	H profile has the UR set to 1 when relating to hotel facilities – being used only by hotel tourists – while the NH profile's one will be set to 0. *Vice versa, the* NH profile's UR is equal to 1 when relating to extra-hotel facilities while the H profile's one will be set to 0. E profile will always have its UR set to 0 not using any accommodation facility.
Food & Beverage	0 – 1	It has been calculated and transformed into a percentage starting from the results of the surveys. The ratio relies on eating at least once in a F&B facility as UR is equal to 1.
Mobility	*Parking*: 0 – 1 *Transportation*: 0 – 10	*Parking*: it has been calculated and transformed into a percentage starting from the results of the surveys (i.e., if one out of three H tourists reaches the destination by car, the UR will be set to 0,3). *Transportation*: it corresponds to the number of public transport trips carried out daily.
Attraction	0 – 1	It has been calculated and transformed into a percentage starting from the results of the surveys. The ratio relies on the average lengths of stay, when visiting the attraction once on a three-day trip will set the UR to 0,3, once on a two-day trip to 0,5, and during the

day to 0,7.

This study highlights a complementary inference of the TCC model outlining sectorial and specific implications and not just an overall condition of the destination. This approach allows for a more targeted and comprehensive analysis of the issues and challenges facing a destination. By identifying sector-specific bottlenecks - such as transportation - tourism stakeholders can develop tailored strategies to address these challenges. Furthermore, by treating these issues as leverage for the enhancement of new strategies in sustainable destination management, this TCC model can help to promote profitable practices that balance economic, environmental, and social factors.

A distinguishing factor in addressing transportation-related bottlenecks involves considering alternatives to investing in physical infrastructure, with a focus on adopting specialized tools within the sector to tackle issues efficiently. This entails gathering and analyzing data on tourism behavior, often through specific services, to optimize strategies cost-effectively. Additionally, this approach involves complementary actions based on the insights derived from such data analysis.

Thus, to boost tourist experiences, the integration of real-time traffic information can provide up-to-the-minute data on traffic conditions to steer clear of congested areas and choose alternative routes to enhance the valuable utilization of transportation resources. Introducing online booking systems enables a streamlined and optimized tourists' engagement with transportation services in advance, leading to multifold benefits when related to reducing wait times and ensuring that tourists can access transportation precisely when needed. For instance, this widely promotes an effective tourism transportation ecosystem aligned with the ethic of convenience. Equally efficient is the implementation of virtual queuing systems, which operate in diminishing wait times for popular transportation services: differently from online booking systems, this tool comes with timely notifications on tourists' devices when to board by having reserved a spot in line. Specifically aimed to extend tourists staying at the destinations, it evolves within the expectations of a digitally connected tourist demographic. The emergence of ride-sharing applications stands out for its far-reaching implications and comprehensive requirements. Being convenient and cost-effective, these applications present an even more compelling substitute for regular transportation. Sharing rides with other tourists is conducive to curtailing the number of cars on the road, alleviating, and mitigating congestion while promoting sustainable habits. This is achieved by the fundamental methodology of the proposed model and analysis, which is to simulate the consequences of various policies to limit tourist flows connected to excess visitor demand on a given tourism subsystem.

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