A Roadmap to Congestion Management in Museums from a Socio-Technical Perspective

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Abstract. Cultural heritage spaces, and in particular museums, constitute a special type of socio-physical systems, where the decision making burden with respect to visitor touring choices, mainly lies on visitor himself. Due to the inherent characteristics of such a system, that embodies both human behaviors as well as physical or technical constraints and requirements, it becomes apparent that a socio-technical perspective should be considered to treat the key problem of congestion management, while improving visitor experience and satisfaction. In this paper, we provide a roadmap to dealing with this issue, by suggesting a realistic visitor behavior modeling approach and promoting alternative and feasible congestion management solutions. Our considerations and mechanisms are founded on and powered by the principles of Prospect Theory and the Tragedy of the Commons, with respect to modeling and capturing visitor behaviors and decision making under potential risks and uncertainties, typically encountered by visitors during their visiting experience. Based on this framework, initially a risk-based visitor time management mechanism is provided, and then pricing is suggested as a valid measure to reduce overcrowding in cultural heritage spaces. Finally, the consequences of people's tendency to overweight small probabilities and underweight large ones, as well as the potential of adopting framing effects by museum curators, on visitor's decision making process are highlighted.

Keywords: Cultural Heritage Spaces · Museums · Visitor Experience · Congestion Management · Socio-Physical Systems · Prospect Theory.

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1 Introduction

The importance of cultural heritage is undeniable, as it reflects people's values, beliefs, knowledge and traditions. Linking the past, the present and the future, cultural heritage embodies treasures inherited from the past that should be bequeathed to future generations. Nowadays, cultural heritage has even more to offer due to the modern way of life. Longer working hours, excessive use of social media platforms, the availability of large numbers of activities and consumer choices lead people to become socially isolated and disconnected from their heritage. As a result, visiting cultural heritage spaces (e.g. museums) can be nothing but beneficial, creating a novel alternative socio-physical system paradigm.

Museums are dynamic learning environments [1, 2] and people always gain useful information and positive experiences during a visit. They offer an ideal window into a world of history and cultures of different countries. They also offer a very positive educational environment where people can enjoy a shared-learning experience with family and friends. Visitors gain experiences and create memories at museums that do not expire and make them happier in the long run. At the same time visitors' experience, often referred to as Quality of Experience (QoE) [3–5], is typically evaluated and/or measured in terms of visitors perception of different aspects, such as utility, satisfaction, and/or efficiency. Though user experience expresses the individual's own perception and could be a subjective metric, this is done with respect to the context - spatial or temporal - and the characteristics - physical or social - of the system that the visitor belongs to. Therefore, this gives rise to strong interdependent behavioral patterns and decision-making processes among museum visitors [6].

One of the key issues and challenges, that directly impacts visitor satisfaction, is the problem of congestion in cultural heritage spaces and especially museums [7, 8]. Crowd density has been shown to be one of the most influential factors, negatively affecting visitor QoE [4] because it results in long queuing, noise and eventually to inability to observe exhibits. Congestion is mostly encountered in well-known and world famous museums, which are known as "superstar" museums. A superstar museum is a "must" attraction for tourists, has a significant number of visitors every year, includes a collection of well-known artists and works, and finally concludes towards a significant positive impact on the local economy [9]. However, even though such museums contain outstanding exhibits, that are valuable and important to humanity, overcrowding prevents visitors from accessing and enjoying them.

Despite the long history of interest in cultural heritage, the problem of museum congestion has not been resolved and it still remains an issue of significant practical and research interest. In this paper, we aim at exactly filling this gap and shed light on museum congestion management problem from a socio-technical perspective. To deal with this, we first suggest a realistic visitor behavior modeling approach and respectively promote alternative and feasible congestion management solutions, stemming from the power and principles of Prospect Theory and the Tragedy of the Commons [10–12].

2 Visitor behavior and their risk choices

In our work, we consider cultural heritage spaces as cyber-physical social systems where people interact with each other, and the behaviour and decisions of one visitor influence and are influenced by others. Moreover, as opposed to other social environments, human experiences in a cultural heritage space are primarily controlled by visitors themselves, as they decide how much time to spend in a museum or which exhibits to observe. Therefore it is important to understand the potentially unknown behaviour tendencies of visitors - especially in terms of decision making - in order to improve their visiting experience.

2.1 Visitor risk choices in a cultural heritage space

Visitor decisions about which exhibits to observe (e.g. popular or non-popular) and how much time to spend in front of them constitute decisions that entail risk. The outcome of visiting a popular exhibit is neither guaranteed nor always positive. The exhibit may be so congested that it may be impossible for visitors to gain any satisfaction from it.

Based on this observation, in our work we classify art works into two main categories: safe and Common Pool Resource (CPR) exhibits. Safe exhibits are less well-known exhibits and thus less congested. Accordingly, we consider the decision of a visitor to be safe when investing time at a safe exhibit because the exhibit will not be surrounded by a lot of people and the visitor will certainly enjoy observing it. In contrast, CPR exhibits are works that are famous worldwide and potentially overcrowded.

In principle, a CPR is a resource that may significantly benefit a group of people, but provides diminished benefits to everyone if each individual pursues his or her own self-interest. A CPR may experience "failure" due to over-utilization (or over-exploitation) with a probability that increases as visitor total time spent (invested) at CPR increases. In case of CPR failure, none of the visitors gain any satisfaction from it, a phenomenon known in the literature, as "Tragedy of the Commons" [12]. Consequently its availability and welfare is governed by the key characteristics of subtractability and non-excludability. A popular exhibit is subtractable because the time a visitor spends observing it, influences negatively (reduces) the ability of being observed by another. At the same time, a famous work-art is non-excludable as all visitors have the right to visit it and no one can be excluded from observing it. We regard as risky the decision of a visitor to invest his/her time at a popular exhibit, because the view of the exhibit may be blocked by others in some cases, and thus the visitor will consider this experience as a potential loss.

With this in mind, we claim that people's behaviour inside a cultural heritage space is not risk neutral. Visitors exhibit either a risk seeking or risk averse behaviour according to circumstances and specifically when they take decisions under uncertainty. While taking into consideration visitor behavioral risk preferences, we adopt Prospect Theory [10] to express visitor QoE in a quantifiable and tractable manner. In the remaining of this work, we regard the portion of

each visitor's available time invested at CPR exhibits, as the investing parameter (i.e. optimizable parameter) that directly impacts museum congestion and consequently user satisfaction (i.e. utility). The remaining percentage of visitor's time is consequently assumed to be consumed at safe exhibits.

2.2 Prospect Theory Basic Properties: Background Information

Prospect Theory is the most widely accepted behavioral model of decision making under risk. It is a Nobel prize winning theory [10], and in a nutshell has four main characteristics:

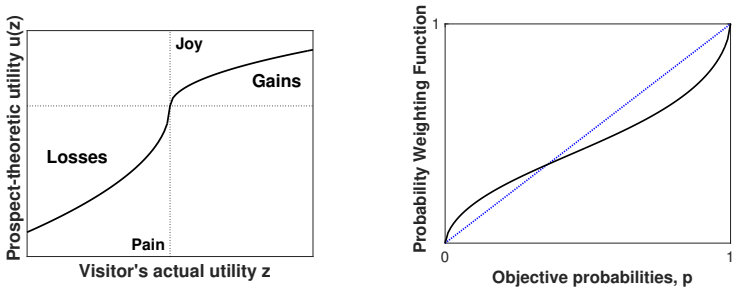
Reference Dependence Prospect Theory declares that people evaluate outcomes, both gains and losses, not as absolute values but with respect to a status quo or baseline, which in principle could be different per visitor (or types of visitors). Based on Kszegi and Rabin's research work [13–15], people use their expectations or beliefs as a reference point to measure losses and gains. For example, in the case of cultural experiences, people may assess their quality by comparing them with previous experiences, or other potential alternative options/choices. In our work, we set the reference point as the visitor perceived satisfaction or utility gained when all of his/her total visiting time t_i^{Max} is invested at safe exhibits and is expressed as follows:

$$z_0 = w_i t_i^{Max} \tag{1}$$

where w_i expresses the importance of safe exhibit for visitor i and arises from the combination of the historical importance of the safe exhibit e_w and the subjective interest of visitor i for the specific safe exhibit I_i, i.e. $w_i = e_w I_i$.

Loss aversion Prospect Theory claims that people take losses into account more than gains. Consequently, an individual experiences comparatively greater discomfort in cases of loss than the joy felt in cases of gain of equal magnitude. Therefore, visitors with high interest in an exhibit (e.g."The Last Supper" of Leonardo da Vinci) would sense sorrow if they were not able to visit or observe it due to congestion that would be comparatively greater than the pleasure they would gain otherwise.

Diminishing sensitivity Diminishing sensitivity signifies that people tend to be loss averse towards gains and risk seeking towards losses. When people experience gains, they prefer not to "gamble", and obtain a rather certain gain, even if there is a possibility of gaining more. In contrast, they prefer to risk over a certain loss. This human behavioral characteristic is expressed via the prospect theoretic utility function which is presented in Fig.1a and is formally defined later in Eq.2. The figure illustrates visitor perceived utility i.e. joy or pain (vertical axis), as a function of a specific uncertain outcome, i.e. gain or loss (horizontal axis). Regarding cultural heritage experiences, we consider gains



(a) (b)

Fig. 1. (a) Prospect-theoretic QoE and (b) Probability weighting function

and losses as the perceived satisfaction a visitor gains during his/her visit in a cultural heritage space.

Probability weighting Probability weighting is the fourth characteristic of Prospect Theory and refers to the probabilities assigned to events. In general, people have difficulty in decoding probabilities due to human psychology and not to a low mathematical background. They tend to assign to outcomes not their objective probabilities but weighted probabilities or decision weights. The solid line in Fig.1b shows the probability weighted function which illustrates the decision weight as a function of the objective probability, p. The graph reveals that the probability weighted function overweights extremely unlike events and underweights events that are likely to happen.

3 Approaches to Museum Congestion

In the following, based on the aforementioned observations and arguments, we present three different approaches to deal with the problem of congestion management in cultural heritage spaces, which could be used either in isolation or in a complementary manner. Especially, since congestion management turns to be a complicated problem, it is suggested that more than one of the proposed solutions may need to be adapted, and thus their correlation and simultaneous consideration is also highlighted in this article.

3.1 Risk-based Visitor Time Management

In the literature, there exist several works that study and evaluate visitor perceived satisfaction either in a qualitative way [3, 16, 17] or in a quantitative way using mathematical functions and formal expressions [4, 18, 19]. However, irrelevant of their nature, the majority of them do not consider visitor behavioral characteristics, and more importantly how such attributes or reactions influence

visitor touring process and overall experience. Such an approach was very recently introduced in [20], where the authors formulated and modeled the overall visitor museum behavior by considering visitor risk preferences and their impact on visitor decision making process. In particular, based on Prospect Theory and properly formulated Prospect Theoretic Utility function (see Eq.2), visitor optimal investment time at CPR exhibits was computed with the objective of maximizing visitor Expected Prospect Theoretic Utility, and reducing the potential negative impacts due to the congestion issue. The Prospect Theoretic Utility function is defined as:

$$u(z) = \begin{cases} (z - z_0)^a, & z \geq z_0 \\ -k(z_0 - z)^b, & z < z_0 \end{cases} \tag{2}$$

where $0 < a \leq 1$, $0 < b \leq 1$, and $k > 1$, while the interpretation and meaning of these parameters are explained below. Specifically, parameter a expresses the visitor sensitivity towards gains whereas parameter b expresses the corresponding sensitivity towards losses. People with greater value of a given some gain, become more satisfied than visitors with lower a. Respectively, people with lower value of b compared to people with higher value of b feel greater sorrow for the same loss. Complementary to this, parameter k signifies the importance someone places on gains and losses. Specifically, people value losses more than gains when $k > 1$ and they weight gains more than losses when $0 \leq k \leq 1$.

The study of visitor optimal investment time based on a Prospect Theoretic approach [20] concluded to very interesting outcomes and give a different, yet realistic, perspective to museum congestion problem. Characteristically, indicative numerical results revealed that visitor heterogeneity in either the sensitivity parameter or the loss aversion value results in an increase in CPR probability of failure. CPR failure can be also provoked by different levels of interest in exhibits among visitors. Moreover, people with a low sensitivity parameter a gain high satisfaction from their visit while tending to invest less time at CPR exhibits. As regards the impact of loss aversion, visitors with a high loss aversion value make shorter visits and are happier when they leave.

Consequently, from a cultural heritage site operator point of view, it is clearly more beneficial:

- to group visitors according to their risk preferences (a and k) in order to accomplish homogeneity among simultaneous visitors at a museum
- to group visitors with respect to their interest in exhibits
- to accommodate visitors with a low sensitivity parameter and visitors with a medium or high loss aversion value.

3.2 Pricing policies - "Pay as you go" model

Another alternative approach to dealing with overcrowding is based on pricing policy mechanisms. The question of charging admission fees is controversial and there are arguments both for and against their implementation. The main

motivating arguments of supporters of free access stem solely from a social or sociological perspective. They claim that cultural heritage spaces should be open to the public and should not exclude any group (i.e. poor or young people). They also argue that free entry raises the number of visitors and consequently increases the prestige of a cultural heritage space.

However, there is significant research that contradicts the above claims. A survey conducted in the British Museum [21] revealed that only 1% of visitors, visited the museum because it was free, and on the question of what they liked or disliked most about their experience, more than 15% of them stated that they disliked the crowds. This survey also illustrated that visitors are prepared to pay more in order to experience less congestion. The study [22] verified that the charging of an entrance fee in museums decreased overall numbers of visitors by 30%, but nevertheless the numbers of low-income visitor families rose significantly instead of falling. Moreover, the authors in [23] demonstrate that the main barrier to young people attending cultural events is not the cost but their belief that art is not an enjoyable or beneficial experience.

Based on the above arguments, in the following, we adopt the perspective that pricing policies constitute a valid measure to reduce overcrowding in cultural heritage spaces, and we consider that visitors may pay according to the duration of their visit, especially if this facilitates and promotes an increase in their cultural benefits and expectations. This belief is clearly supported and reflected in Goudrian and Gerrit's study [22] which demonstrated that the entrance fee does not filter out low-income visitors as stated before, but rather short stay visitors. Classification of visitors into short and long stay visitors is found in the literature [24, 25] and distinguishes them according to their visiting time. The results of [25] showed that both types of visitors tend to visit the same number of popular exhibits but the longer stay visitors tend to spend more time observing them. Surprisingly, it was also revealed that longest stay visitors visit fewer exhibits on average compared to short stay visitors. Therefore, visitors who extend their stay in a museum should be charged accordingly, especially when investing great portion of their time in visiting CPR exhibits. In other words, the cost that their presence imposes on other visitors should be transferred back to them.

Therefore, we suggest a pricing fee which will be directly proportional to the visitor invested time t_i at the CPR. Initial indicative numerical results of applying such a time-based pricing approach in a prospect theoretic framework, actually confirm that pricing leads to a significant decrease in CPR failure probability and specifically CPR failure probability decreases as the price charged to visitors increases.

3.3 Cumulative Prospect Theory and Framing effects impact

As mentioned before, decision making analysis, especially under risks and uncertainty, is of high research interest among various disciplines i.e. mathematics, statistics, economics, political science, sociology and psychology [26]. With reference to museums, risky prospects, such as finding congestion at a CPR exhibit or

CPR failure, are characterized by possible outcomes i.e. the CPR is congested or the CPR is not congested, as well as the probabilities of these outcomes. Therefore, a prospect f is expressed as the sequence of pairs (x, p) where x is the outcome and p is its objective probability. However, the fourth key element of Prospect Theory, probability weighting (section 2.2) illustrates that people may not value outcomes by their objective probability but by a transformed probability or decision weight. In particular, a modified version of Prospect Theory, namely Cumulative Prospect Theory [27], proposes a probability weighting function (Eq.3), which is depicted by the solid line in Fig. 1b. As the dotted line corresponds to the expected utility, it is obvious from the graph that people overweight low probabilities and underweight high probabilities. The inverse-S shape of the weighting function which is initially concave and then turns convex is responsible for the decreased sensitivity to changes in the middle of the scale.

Therefore the proposed modified probability weighting function is given by:

$$\pi(p) = \begin{cases} \frac{p^{\gamma}}{[p^{\gamma}+(1-p^{\gamma})]^{\frac{1}{\gamma}}}, & x \geq x_0 \\ \frac{p^{\delta}}{[p^{\delta}+(1-p^{\delta})]^{\frac{1}{\delta}}}, & x < x_0 \end{cases} \tag{3}$$

where p is the probability of the outcome and γ, δ are positive parameters that express the level of distortion in probability judgment in the decision making process. In contrast to Prospect Theory, Cumulative Prospect Theory allows the probabilities to enter the utility function Eq.2 non linearly but using the above weighting function (as expressed by Eq.3), which considers people's tendency to overweight small probabilities and underweight large probabilities, in an attempt to produce even more pragmatic results.

In order to further comprehend visitor risk attitudes, we propose the designation of a museum routing mechanism based on Cumulative Prospect Theory to investigate visitors' choices, when congestion information is provided. Electronic devices installed at specific junctions in the museum would inform visitors about the overcrowding they would meet. Under that setting, visitors would have to deal with a choice under risk only, rather than under uncertainty, because the probabilities of the possible outcomes would be known. Similar studies have already been conducted in other fields [28], where numerical results revealed that people become risk seeking when outcome probabilities are high, and risk averse when outcome probabilities are lower.

In the following, we also argue that a complementary and highly promising approach towards reducing congestion is based on the potential of properly influencing visitors decisions towards being redirected to different floors, rooms or buildings of a "superstar" museum during busy days or peak hours. To this end, we suggest the usage and application of framing effects which is part of the development of Prospect Theory [29]. Specifically, it highlights either the positive or the negative aspects of the available choices of a decision problem (e.g. either presenting the museum as 75% full or as 25% empty). Therefore, risky prospects can be respectively framed either as gains or losses. The available choices and the potential outcomes are always the same, however the way available choices are

framed or described lead to a potentially different decision. Although changing the description of a prospect should not change the decision in principle, framing effects illustrate that not only is this possible but more importantly it can also be predicted.

4 Concluding Remarks

The importance of cultural heritage is vital for humanity, as a means of sustaining and enhancing our integrity as people. In this paper, in order to contribute towards the improved visitor experience throughout a cultural heritage space touring, we presented alternative approaches to handle museum congestion issue, which is one of the key problems negatively affecting visiting experience.

Museums are socio-physical spaces where visitors behaviour and decisions are influenced and being influenced by others. As visitors exhibit either a risk seeking or risk averse behaviour, we argued that the understanding of visitor behavioral characteristics and risk preferences, is vital for improving their perceived satisfaction. Moreover, we suggested the application of a pricing policy as an effective approach to address overcrowding issue and decrease the "failure" probability especially of popular exhibits. Finally, we discussed the potential of framing effects as an additional mechanism to treat congestion problem, by implicitly influencing visitor touring decisions and thus permitting the better planning and control of traffic withing a cultural heritage space, especially during busy days and peak hours.

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