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A Theory of Interior Peaks: Activity Sequencing and Selection for Service Design

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Abstract. ***Problem definition*:** Putting customer experience at the heart of service design has become a governing principle of today's "experience economy." Echoing this principle, our paper addresses a service designer's problem of how to select and sequence activities in designing a service package. ***Academic/practical relevance:*** Empirical literature shows an ideal sequence often entails an *interior peak*; that is, the peak (i.e., highest-utility) activity is placed neither at the beginning nor the end of the package. Theoretic literature, by contrast, advocates placing the peak activity either at the beginning or at the end. Our paper bridges this gap by developing a theory accounting for interior peaks. It also provides managerial implications for activity sequencing and selection. ***Methodology*:** We model the activity sequencing and selection problem as a nonlinear optimization problem and reformulate its objective as an additive function to generate structural insights. ***Results*:** We show that heterogeneity in memory decay explains the phenomenon of interior peaks. The optimal sequence is in either an "IU" or "UI" shape. An interior peak is optimal when the memory decay rate of the peak activity is neither too high nor too low. ***Managerial implications*:** Our research sheds light on service sequencing by weighing the phenomenon of interior peaks. In the presence of an interior peak, we show it is optimal to schedule a low point immediately before or after the peak activity, creating a contrast in customer experience. In addition, interior peaks arise partly because the peak activity is more memorable than others. Guided by this logic, as the peak activity becomes even more memorable, one might be tempted to move it to an earlier slot; we show that, counterintuitively, moving it to a later slot can be optimal. Our research also provides implications for activity selection by showing the optimal portfolio may consist of activities with the highest- and lowest-utility values but not those with medium values.

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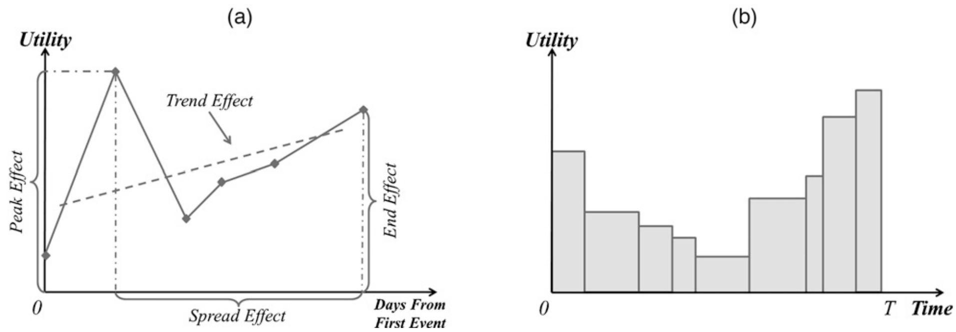
> We're great at sequencing. I realized at a young age that sequence in an album is almost as important as the songs that are on the album. And I know that got lost on the Internet with people just being able to go on and buy one song, but I think now we're going to apply that system back into the listening experience.
>
> Dr. Dre in an interview with *Time* magazine by Guzmán (2014)

1. Introduction

We live in an "experience economy." As Gillian Tett (2016) elucidates in a *Financial Times* column, the internet has largely diminished the exclusivity of owning luxury goods. As a result, "what remains more exclusive are not the accumulation of goods but the accumulation of memories." As Exhibit A of this view, Sarah Quinlan, a Mastercard executive, estimates future growth in consumer spending will be mostly from the areas of "experiences" such as travel and leisure. For this reason, the bandwidth of service operations has now expanded beyond delivering basic customer needs to include an emphasis on "customer delight" (Rawson et al. 2013).

Two crucial decisions in service design are (1) how to select activities and (2) how to sequence activities. In particular, activity sequencing has attracted much attention from practitioners and service operations scholars alike because "how a company sequences high points in relation to low points can materially change

Figure 1. Illustration of the Divide Between Empirical and Theoretic Literature



Notes. (a) Empirically constructed optimal schedule (Dixon and Verma 2013). (b) Theoretically optimal schedule (Das Gupta et al. 2016).

the perception of the service received" (Bhattacharjee et al. 2016). Dixon and Verma (2013) empirically investigate service bundles at a performing arts venue and find that an ideal schedule follows the pattern illustrated in Figure 1(a), with the peak activity (i.e., the highest-utility activity) scheduled neither at the beginning nor at the end. Hereafter, we refer to this type of schedule as an *interior-peak schedule*.

Echoing the empirical literature, anecdotal evidence for interior peaks exists in performance arts. The Super Bowl halftime shows, for example, often do not conclude with the most popular songs. In the 1993 Super Bowl halftime show, Michael Jackson performed five songs; the peak arrived when, lighting up the Rose Bowl with his signature moonwalk, he performed his second song "Billie Jean," which is among his most popular songs and netted numerous honors, including two Grammy Awards (Greenberg 2012). In a recent Super Bowl halftime show, flying down from the top of the NRG Stadium, Lady Gaga sang her symbolic track "Poker Face" as the event reached its high point, following "God Bless America" and ahead of "Bad Romance" (Bakare 2017).

The theoretic literature, however, has yet to offer an explanation for interior peaks. Notably, Das Gupta et al. (2016) present a model based on two psychological concepts, acclimation and memory delay (AMD), and show the optimal schedule follows a (weakly) U shape with respect to the utility of each activity, as illustrated in Figure 1(b). They show the peak activity should be scheduled at either the beginning or the end, so an interior-peak schedule cannot be optimal.

Our research is motivated by this divide between empirical and theoretical findings regarding the placement of the peak activity. As such, our model offers the first theoretic explanation for interior peaks.

Our model follows the framework of Das Gupta et al. (2016), who assume all activities possess the same memory decay rate (i.e., they are equally memorable), which however, deviates from what service operations practitioners, such as Bhattacharjee et al. (2016, p. 3), commonly observe: "Customers tend to disproportionately recall the high and low points of their customer journeys and not all the individual aspects of it." The memory and cognition literature provides evidence that the intensity of an event can impact its memory recall (Burke et al. 1992, Sharot and Phelps 2004). Gold (1987, p. 151) contends, "Evidently we remember important events, and often the circumstances surrounding those events, better than other events, even if the latter occurred more recently." Stated differently, a high-intensity activity is more memorable than other activities. By incorporating this consideration that the peak activity is more memorable than other activities, we show an interior peak can arise in an optimal schedule. Without such heterogeneity, an interior peak can never be optimal. Through this contrast, we demonstrate that the heterogeneity in the memory decay rate is a key driver of the interior-peak phenomenon.

Our theory of interior peaks has rich implications for sequencing both peak and nonpeak activities when designing a service package. We characterize the optimal sequence and show that in the presence of an interior peak, it is optimal to schedule a low point before or after the peak activity. The low point leading up to the peak creates a "pleasant surprise" and improves the contribution of the peak activity to the remembered utility. Likewise, having experienced the peak activity, a low point reduces the customer's reference level, allowing room for improved perceived utility during the rest of the service package. In addition, our research elucidates the effect of the memory decay rate of the peak activity on the optimal schedule. As the peak activity becomes more memorable, all else being equal, one might be tempted to place the peak activity at an earlier slot. We find, surprisingly, the service provider can be better off scheduling the peak activity at a *later* slot.

Our theory of interior peaks also has implications for activity selection. We examine a problem in which the service provider can select a number of activities to build a service package. We find the optimal portfolio may consist of the highest- and lowest-utility activities, but not the medium-utility ones. This result echoes our findings on activity sequencing because a portfolio of high and low points facilitates the creation of a sequence with contrasts.

1.1. Literature

The service design literature has placed optimizing customer experience at its center. We refer the reader to Bitran et al. (2008), Karmarkar (2015), and St. Peter et al. (2015) for reviews of the service design literature that incorporates customer experiences. Broadly speaking, there are two approaches to modeling customer experience. One approach is to empirically examine each customer's "experience profile" (Ariely and Carmon 2000), which states a customer cannot remember all the details of a service experience but can recall several gestalt characteristics (Ariely 1998). Dixon and Verma (2013) empirically show the effect of activity sequencing on customers' experience profile. Another approach to modeling customer experience is through incorporating various psychological phenomena, especially (1) acclimation and (2) memory decay.[1] The acclimation effect has been examined by Baucells and Bellezza (2016), who study the anticipation-event-recall model, and by Tereyağoğlu et al. (2018), who address multiattribute loss aversion and reference dependence. The memory decay effect, proposed in the seminal work by Ebbinghaus (1913), finds wide applications in the service operations literature (Shafer et al. 2001, Cohen-Hillel et al. 2019, Ramdas et al. 2018). Both approaches have deepened our understanding of service design. However, as aforementioned, when examined together, they present a conflicting picture. Our paper bridges this gap by extending the AMD theoretic framework (the second approach) while providing theoretic support for empirical findings (the first approach).

2. Model

We consider a service design problem consisting of selecting and sequencing activities to maximize a customer's remembered utility from the service package. The service designer begins by choosing n activities from m candidate activities and then proceeds to make the sequencing decision $\boldsymbol{\pi} = \{\pi[1], \ldots, \pi[n]\}$, where $\pi[i]$ is the ith selected activity in the schedule. Until Section 5, for simplicity of analysis and notation, we restrict our attention to the case in which all the activities have been chosen (i.e., $m = n$). Thus, for now, the service designer's focus will be on activity sequencing.

Each selected activity $i \in \{1, \ldots, n\}$ has a unidimensional given utility u_i and a fixed duration τ_i. The activities are indexed in an increasing order of the utilities: that is, $u_1 \le u_2 \le \ldots \le u_{n-1} < u_n$. The firm assembles a service package with a planning time of $T = \sum_{i=1}^{n} \tau_i$ to maximize each customer's ex post satisfaction. We refer to activity n as the *peak activity*. We denote by $\bar{t}_{\pi[i]} = \sum_{j=1}^{i} \tau_{\pi[j]}$ the completion time of activity $\pi[i]$ and by $t_{\pi[i]} = \sum_{j=i}^{n} \tau_{\pi[j]}$ the duration from the starting time of activity $\pi[i]$ until the end of the service package. Figure 2 illustrates the notation.

We adopt the AMD framework to quantify customers' retrospective perception of a service package. The framework represents the accumulated remembered utility of the package as drawn from two psychological concepts, namely (1) acclimation and (2) memory decay.

First, the acclimation process reflects the psychological phenomenon whereby with the same average utility, customers prefer positively changing utilities to a constant utility. Denote by $\alpha > 0$ the acclimation rate.[2] For a given schedule $\boldsymbol{\pi}$, we denote by $b_{\boldsymbol{\pi}}(\bar{t})$ each customer's reference level at time $\hat{t}$. For brevity of notation, we omit π in the subscripts and use $b(\bar{t})$, $\bar{t}_j$, and t_j to represent $b_{\boldsymbol{\pi}}(\bar{t})$, $\bar{t}_{\pi[j]}$, and $t_{\pi[j]}$, respectively. In modeling the acclimation process, we follow the AMD model by assuming the change rate of the reference point is proportional to the difference between the utility and the reference level; that is, the change rate of reference level $b(\bar{t})$ for $\bar{t} \in [\bar{t}_{i-1}, \bar{t}_i]$ is

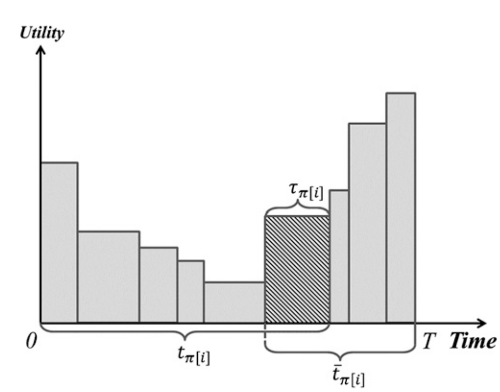
$$\frac{db(\bar{t})}{d\bar{t}} = \alpha(u_{\pi[i]} - b(\bar{t})). \tag{1}$$

Using (1), we express $b(\bar{t})$, the reference point, and $v_{\pi[i]}(\bar{t})$, the instantaneous utility of the ith activity for $\bar{t} \in [\bar{t}_{i-1}, \bar{t}_i]$, as

$$b(\bar{t}) = u_{\pi[i]} - \left((u_{\pi[1]} - b(0)) + \sum_{j=2}^{i}(u_{\pi[j]} - u_{\pi[j-1]})e^{\alpha \bar{t}_{j-1}}\right)e^{-\alpha\bar{t}}, \tag{2}$$

$$v_{\pi[i]}(\bar{t}) = (u_{\pi[1]} - b(0))e^{-\alpha\bar{t}} + \sum_{j=2}^{i}(u_{\pi[j]} - u_{\pi[j-1]})e^{-\alpha(\bar{t}-\bar{t}_{j-1})}. \tag{3}$$

Figure 2. Key Time Intervals of the ith Activity



Next, the memory decay process reflects the phenomenon whereby the remembered utility of an activity decreases with the passage of time. In the AMD model, this phenomenon is captured by an exponential memory decay process with a rate of ω. Drawing from the psychology literature (e.g., Burke et al. 1992, Sharot and Phelps 2004), we propose a model with nonhomogeneous memory decay, such that the peak activity has a lower memory decay rate ω_n than others do; that is, $0 < \omega_n < \omega$.[3] We focus on the interesting cases in which $\omega \neq \alpha$ and $\omega_n \neq \alpha$.

Let $\omega_{\pi[i]} \in [0, \infty)$ denote the memory decay rate for the ith activity in the schedule $\boldsymbol{\pi}$, and let p_π denote the position of the peak activity in a given schedule $\boldsymbol{\pi}$. We define a customer's cumulative remembered utility associated with a schedule $\boldsymbol{\pi}$ as

$$S(\boldsymbol{\pi}) = \sum_{i=1}^{n} \int_{\bar{t}_{i-1}}^{\bar{t}_i} v_{\pi[i]}(t) e^{-\omega_{\pi[i]}(T-t)} dt, \tag{4}$$

where $\omega_{\pi[i]} = \omega$ if $i \neq p_\pi$ and $\omega_{\pi[i]} = \omega_n$ if $i = p_\pi$. Clearly, the objective function (4) is not directly separable over individual activities. We reformulate (4) as an additive form in the following:

$$\max_{\pi} S(\boldsymbol{\pi}) = \sum_{i=1}^{n} u_{\pi[i]} w_i(\alpha, \omega, \omega_n, p_\pi); \tag{5}$$

see the online appendix for details of the reformulation. We observe from (5) that the weight of $u_{\pi[i]}$, denoted by $w_i(\alpha, \omega, \omega_n, p_\pi)$, depends on the basic parameters α, ω, ω_n and p_π but not on $u_{\pi[j]}$ for $i, j = 1, \cdots, n$ and $i \neq j$. This additive property allows us to analytically characterize the optimal activity selection and sequencing decisions.

3. Heterogeneous Memory Decay and Optimality of Interior Peaks

We now address an important research question that motivates the study: Can an interior-peak schedule arise in the optimal solution to some service design problem? In addressing this question, we bridge the gap between empirical evidence (e.g., Dixon and Verma 2013) and analytical predictions (e.g., Das Gupta et al. 2016) related to the phenomenon of interior peaks.

First, we define the concept of interior-peak schedules.

Definition 1. A schedule $\boldsymbol{\pi}$ has an *interior peak* if $p_\pi \in \{2, \ldots, n-1\}$; we refer to such a schedule as an *interior-peak schedule.*

Deriving the optimality condition of interior peaks is a herculean task for a general activity-sequencing problem. Instead, we consider a case with three chosen activities with utility values of u_1, u_2, and u_3 ($u_1 < u_2 < u_3$); all durations are normalized to one. We define a time threshold

$$T_1(t_{p_\pi}) = \left(\frac{\ln(\omega^2) - \ln(\alpha^2(1 + (\omega - \alpha)\Psi(t_{p_\pi})))}{\omega - \alpha}\right)^+, \tag{6}$$

where

$$\Psi(t_{p_\pi}) = \frac{e^{(\alpha-\omega_n)(t_{p_\pi}-\tau_n)} - e^{(\alpha-\omega_n)t_{p_\pi}}}{\omega_n - \alpha} - \frac{e^{(\alpha-\omega)(t_{p_\pi}-\tau_n)} - e^{(\alpha-\omega)t_{p_\pi}}}{\omega - \alpha};$$

see the online appendix for discussions of $T_1(t_{p_\pi})$ and $\Psi(t_{p_\pi})$. In Lemma 1, we provide a sufficient condition for the interior-peak schedule $\{1,3,2\}$ to be optimal. The proof of Lemma 1, as with other technical results and proofs, is in the online appendix.

Lemma 1. *The interior-peak schedule* $\{1,3,2\}$ *is the unique optimal schedule, if the following conditions are satisfied:* (i) $T_1(1) > 3$, (ii) $\alpha > \omega_n$, *and* (iii) u_2/u_1 *is sufficiently large.*

Lemma 1 suggests that interior peaks can be optimal and are more likely to be so when the utility values are sufficiently different across activities. The intuition of this result is that the interior-peak schedule $\{1,3,2\}$ entails a low point (activity 1) followed by an ascent to the peak (activity 3) and then, a descent to a medium point (activity 2). Because the descent is more memorable than the ascent, for the benefit from the ascent to outweigh the loss from the descent, activity 2 needs to generate sufficiently high utility relative to activity 1.

Note that interior peaks can still arise even when these sufficient conditions in Lemma 1 are violated. Thus, we numerically explore four cases with utility values (u_1, u_2, u_3) drawn from the set of $\{(0.1, 2.9, 3.0), (0.5, 2.5, 3.0), (1.0, 2.0, 3.0), (1.5, 1.5, 3.0)\}$. We randomly sample 40 instances from $(0, 1]$ for each of parameters α, ω, and ω_n and test the optimality of interior-peak schedules in each case. We report our finding for each combination of the first two conditions in Lemma 1. In each cell of Table 1, the first figure represents the number of cases with optimal interior-peak schedules, and the second represents the percentage of such cases among all the feasible cases. We can see from the table that when $(u_1, u_2, u_3) = (0.1, 2.9, 3.0)$, for scenarios satisfying conditions (i) and (ii) in Lemma 1, then 100% of the optimal schedules possess interior peaks. In this condition, schedule $\{1,3,2\}$ meets the requirement in Lemma 1, and we can see it does not require u_2/u_1 to be extremely high. As u_2/u_1 decreases, the percentage of optimal interior-peak schedules decreases. This finding suggests the interior peak is more likely to arise in the presence of a high-utility nonpeak activity, in which case scheduling the peak activity in the interior and scheduling the

Table 1. Occurrence of Optima Interior Peaks

	(u_1, u_2, u_3)			
Satisfied conditions in Lemma 1	$(0.1, 2.9, 3.0)$	$(0.5, 2.5, 3.0)$	$(1.0, 2.0, 3.0)$	$(1.5, 1.5, 3.0)$
(i) and (ii)	1,329, 100%	888, 66.82%	357, 26.86%	0, 0
Only (i)	3,866, 94.85%	2,482, 60.89%	1,175, 28.83%	220, 5.40%
Only (ii)	18,529, 93.77%	11,578, 58.59%	2,199, 11.13%	9, 0.05%
None	26,826, 88.19%	15,340, 50.43%	3,612, 11.87%	333, 0.11%

second highest-utility activity at the end can be optimal. In addition, we observe from Table 1 that even if neither condition (i) nor (ii) is satisfied, interior-peak schedules may nevertheless arise as optimal.

Next, we investigate the optimality of interior peaks for the case of $(u_1, u_2, u_3) = (1, 2, 3)$ without imposing additional constraints. In Figure 3, we use a hallowed circle to represent each instance in which an interior-peak schedule is optimal. We observe that interior peaks are more likely to be optimal when ω_n is neither very small nor very large; the same observation may be made in terms of α.

Drawing on these observations, we answer the question that we began with in this section.

Proposition 1. *Under heterogeneous memory decay rates, scenarios exist in which an interior-peak schedule is optimal; under homogeneous memory decay rates, however, an interior-peak schedule can never be optimal.*

Stated differently, heterogeneous memory decay explains the optimality of interior-peak schedules.

4. Implications for Activity Sequencing

Having established the possibility of interior-peak optimality, we now provide managerial implications for activity sequencing in view of the existence of an interior peak. Section 4.1 discusses how to sequence the nonpeak activities. Section 4.2 discusses the effect of the memory decay rate of the peak activity on its optimal position.

4.1. Sequencing of Nonpeak Activities

We now present a structural property of the optimal schedule for a given set of activities. First, we define several shapes to describe the optimal schedule. We say a schedule is *U shaped* if the activities are scheduled first in a crescendo (i.e., increasing) sequence in terms of their utilities, followed by a diminuendo (i.e., decreasing) sequence; clearly, crescendo and diminuendo schedules are two special cases of the U-shaped schedule. Related to a U-shaped schedule, we say a schedule is *UI shaped* if the activities before the peak are in a U-shaped sequence in terms of their utilities and the activities after the peak are in a crescendo sequence. Similarly, we say a schedule is *IU shaped* if the activities before the peak are in a diminuendo sequence in terms of their utilities and the activities after the peak are in a U-shaped sequence.

Proposition 2, in which

$$T_0 \triangleq \frac{\ln \omega - \ln \alpha}{\omega - \alpha},$$

characterizes the optimal schedule.

Proposition 2. *The optimal schedule π^* is in either a UI or IU shape. A UI-shaped schedule is optimal as long as $T \le 2T_0$; a strictly IU-shaped schedule can be optimal only when $T > 2T_0$.*

Figure 4 illustrates the optimal UI- and IU-shaped schedules, in which the shaded bars represent the peak activity. This optimality of UI- and IU-shaped schedules has important implications for the service design problem. It suggests that scheduling a service package with a "jump" or "drop" in the utility before or after the peak, instead of a gradual change, is desirable. The sudden jump leading up to the peak creates an unexpectedly pleasant service experience. In a similar fashion, having experienced the peak activity, the customer experiences a drop that "resets" the customer's reference level, allowing better enjoyment of the remaining part of the service package.

4.2. Nonmonotone Change in the Optimal Peak Position

Next, we examine the effect of the memory decay rate of the peak activity on its optimal position. Interior peaks arise partly because the peak activity is more memorable than others. Guided by this logic, as the peak activity becomes even more memorable, one might be tempted to move it to an earlier slot. Proposition 3, however, states this may not always be the case.

Proposition 3. *As the memory decay rate of the peak activity increases, the optimal schedule of the peak activity can change in a nonmonotone fashion. That is, the optimal start time of the peak activity can either increase or decrease in ω_n.*

We have conducted extensive computational experiments to illustrate Proposition 3, with the parameters provided in the online appendix. Figure 5 describes the change in the optimal peak position for both scenarios 1 and 2, where $\alpha = 0.075$ and $\omega = 0.1$ in scenario 1 and $\alpha = 0.3$ and $\omega = 0.4$ in scenario 2. In particular, in

Figure 3. Illustration of Interior-Peak Schedules in Optimal Service Design

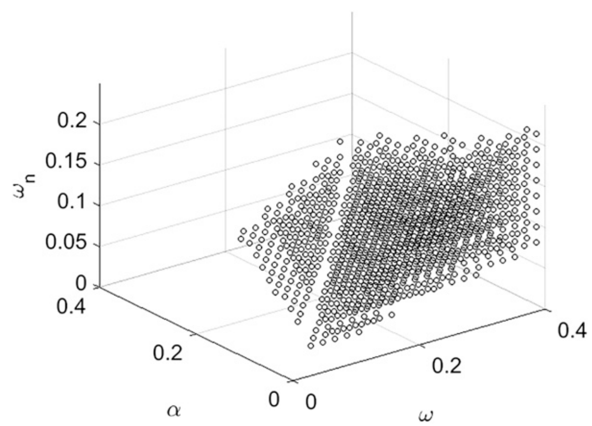
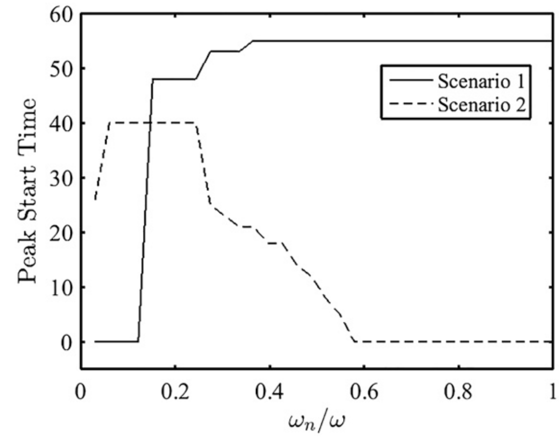


Figure 5. Comparison Across Scenarios 1 and 2: The Impact of ω_n on the Peak Start Time



scenario 2, as ω_n increases, the optimal starting time of the peak activity first becomes later and then earlier. In this case, the optimal position of the peak activity changes in a nonmonotone fashion. The key difference between scenarios 1 and 2 lies in the duration of the peak activity—5 and 20 in scenarios 1 and 2, respectively—with the same package duration of 60. In scenario 2, because of the acclimation effect, a long activity, despite its high utility, may lead to low remembered utility. Therefore, a tension exists between maximizing the remembered utility from the peak activity and that from the nonpeak activities.

Furthermore, we investigate the condition of such a nonmonotone change. We consider a service design problem consisting of seven activities and generate 150 instances of the problem. For each instance, the utility values are randomly drawn from a gamma distribution with a shape parameter of $k = 2$ and a scale parameter of $\theta = 2$. We consider five situations in which the peak activity has the length {2.4, 4.8, 7.2, 9.6, 12} and the durations of the remaining activities are randomly generated such that the planning times are all fixed to 24. We report the percentage of the cases with nonmonotone changes in the optimal peak position in Table 2.

The optimal position of the peak activity may change in a nonmonotone fashion because of the intricate trade-off between maximizing the remembered utility deriving from the peak activity and that from other activities. Table 2 shows such a nonmonotone change is more likely to arise when τ_n exceeds $2T_0$, suggesting the duration of the peak activity is a key driver. This observation can be explained by the asymmetric impacts of acclimation and memory decay in our model: When the duration of the peak activity is sufficiently long, memory decay has a more significant impact. In addition, the condition of nonmonotone change depends on α and ω; see, for example, the contrast between the case with $(\alpha, \omega) = (0.2, 0.5)$ versus that with $(\alpha, \omega) = (0.5, 0.2)$. When $\alpha > \omega$, more cases satisfy $\omega_n < \alpha$; nonmonotone changes are thus more likely (Figure 6).

Figure 4. Illustration of UI- and IU-Shaped Schedules

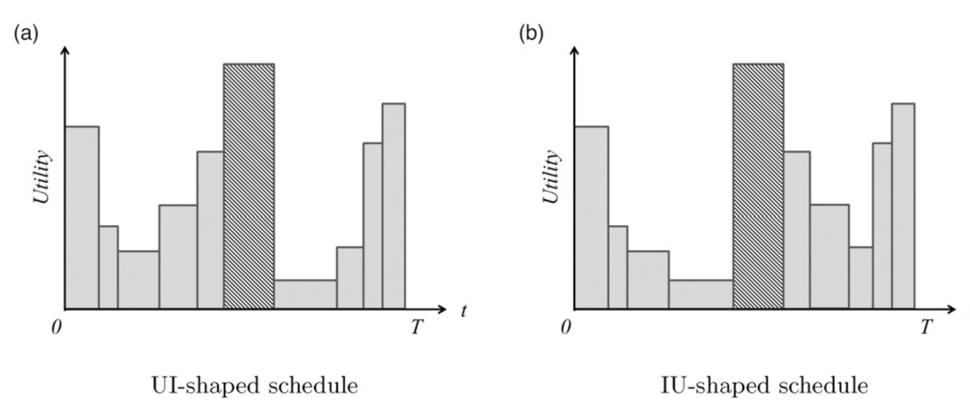


Table 2. Percentage of Cases with Nonmonotone Peak Position Changes (Percentage)

		τ_n				
(α, ω)	T_0	2.4	4.8	7.2	9.6	12
(0.2, 50)	0.11	0	0	0	0	0
(0.2, 5)	0.67	0	0	0	0	0
(0.2, 0.5)	3.05	0	0	2.00	8.67	24.67
(50, 0.2)	0.11	6.67	16.00	13.33	4.00	0
(5, 0.2)	0.67	10.67	34.67	32.00	26.67	22.67
(0.5, 0.2)	3.05	0	1.33	12.00	21.67	26.33

5. Implications for Activity Selection

So far, we have focused on activity sequencing. We now expand our scope to include activity selection. The service designer chooses n activities from m candidate activities to assemble a service package before sequencing them. The service designer aims to maximize the customer's remembered utility by determining a portfolio $\boldsymbol{x} = \{x[1], \ldots, x[m]\}$, where $x[i]$ is a binary decision variable such that $x[i] = 1$ indicates the ith activity is selected and $x[i] = 0$ indicates otherwise, and a schedule $\boldsymbol{\pi}$ (defined in Section 2) of the selected activities.

To generate structural insights into activity selection, we consider the situation in which each activity has an identical duration of τ. In this condition, n time slots exist, and we have $n\tau = T$. An interesting question for future research entails determining the optimal number of activities when the total duration of the service package is variable; we expect our main findings to hold qualitatively.

Proposition 4 presents the optimal activity selection rule. For ease of exposition, we define i as the number of positive weights (i.e., $i = \sum_{k=1}^{n} \mathbb{1}_{w_k > 0}$) in the optimal schedule.

Proposition 4.

i. *Under nonhomogeneous memory decay rates, given peak start time p_π, selecting activity $\{1, \ldots, n-i\}$ and activity $\{m-i+1, \ldots, m\}$ is optimal. In particular, if $T > T_0 + \tau_n$, it is optimal to select a portfolio of highest- and lowest-utility activities (i.e., $i < n$).*

ii. *Under homogeneous memory decay rates, it is optimal to select activity $\{m-n+1, \ldots, m\}$ if $T \leq T_0$; otherwise, it is optimal to select activity $\{1, \ldots, n-i\}$ and activity $\{m-i+1, \ldots, m\}$.*

Proposition 4 states it is optimal to select a portfolio of activities with the highest-and lowest-utility values; the selected activities are in two consecutive sets. The highest-utility activities serve to provide the customer with a satisfying service experience, whereas the lowest-utility activities serve to create a contrast with the highest-utility activities. Under homogeneous memory decay rates, the two sets degenerate to one when the duration is sufficiently short (i.e., $T \leq T_0$). Under heterogeneous memory decay rates, however, it is challenging to analytically derive the exact conditions under which two consecutive sets degenerate to one. Fortunately, we are able to provide a sufficient condition (i.e., $T > T_0 + \tau_n$). Next, we provide the optimal sequence.

Corollary 1. *In the optimal solution to the service design problem, given peak position p_π, the selected activities are ordered according to an ascending sequence of the weight $\boldsymbol{w}$.*

Next, we conduct a numerical study of the activity selection problem with eight activities $\{1, \ldots, 8\}$, with $u_i = i$ and $\tau_i = 3$ for $i = 1, \cdots, 8$. Suppose the service designer is required to select $n = 5$ activities. We consider four cases when $\omega_n/\omega = \{0.1, 0.5, 0.9, 1\}$. We present the optimal activity selection in Table 3. An activity is marked if it is selected.

A few observations can now be made from Table 3. First, when T_0 is sufficiently large, selecting the highest-utility activities is optimal, whereas when T_0 is sufficiently small, selecting both highest- and lowest-utility activities—and skipping the medium-utility activities—is optimal. This observation suggests the relationship

Figure 6. Change in the Optimal Peak Position as ω_n Increases

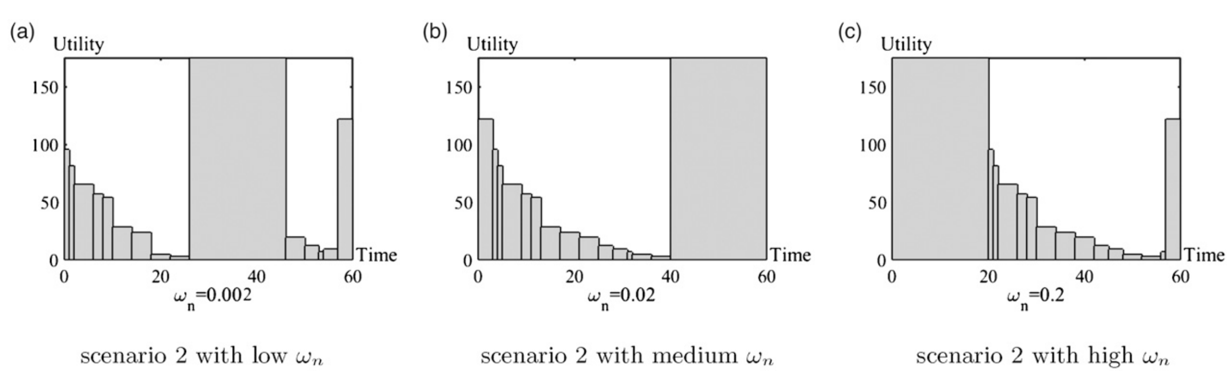


Table 3. Optimal Activity Selection (Marked by Circled Numbers)

$(\alpha,\ \omega)$	T_0	ω_n/ω			
		0.1	0.5	0.9	1
(0.2, 0.5)	3.06	①②③ 4 5 6 ⑦⑧	①②③④ 5 6 7 ⑧	①②③④ 5 6 7 ⑧	①②③④ 5 6 7 ⑧
(0.2, 0.05)	9.24	① 2 3 4 ⑤⑥⑦⑧	①② 3 4 5 ⑥⑦⑧	①② 3 4 5 ⑥⑦⑧	①② 3 4 5 ⑥⑦⑧
(0.2, 0.005)	18.91	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧
(0.2, 0.0005)	30.31	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧
(0.5, 0.2)	3.06	①②③ 4 5 6 ⑦⑧	①②③④ 5 6 7 ⑧	①②③④ 5 6 7 ⑧	①②③④ 5 6 7 ⑧
(0.05, 0.2)	9.24	① 2 3 4 ⑤⑥⑦⑧	①② 3 4 5 ⑥⑦⑧	①② 3 4 5 ⑥⑦⑧	①② 3 4 5 ⑥⑦⑧
(0.005, 0.2)	18.91	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧
(0.0005, 0.2)	30.31	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧	1 2 3 ④⑤⑥⑦⑧

between T and T_0 plays an instrumental role in the service selection. When the package has a long duration relative to T_0, choosing the highest-utility activities is suboptimal because doing so makes it hard to create "jumps." When the package has a short duration relative to T_0, however, choosing the highest-utility activities is optimal. Second, under the same value of ω_n/ω, the optimal activity selection problems under symmetric parameters (e.g., (0.2, 0.5) and (0.5, 0.2)) yield the same solution to the activity selection problem, although the optimal schedule can be different. This observation is consistent with Proposition 4. Third, given $(\alpha,\ \omega)$, when ω_n is small, selecting more highest-utility activities is more likely to be optimal. The intuition is that with a relatively small ω_n, memory decay is less consequential, so the peak activity can move to an earlier time slot. Thus, the designer can schedule more high-utility activities near the end of the event to maximize the customer's remembered utility.

Our result on activity selection reveals that the length of a service package can impact the optimal portfolio. For a sufficiently long package, the customer may prefer a portfolio consisting of both attractive and nonattractive activities, rather than one consisting purely of the most attractive activities. This result echoes our earlier findings on activity sequencing—a package offering a mixture of high and low points facilitates the creation of a sequence with contrasts.

6. Conclusions

Designing customers' service experience has become a central focus of the service industry. One key decision in service design entails the scheduling of a series of activities in a service package. Recent service operations literature has both empirically and analytically examined the optimal sequence of activities to maximize the retrospective perception of the package. However, a striking gap has emerged in this burgeoning literature: Whereas the descriptive literature (Dixon and Verma 2013) contends that optimal schedules may have *interior peaks*, the normative literature (Das Gupta et al. 2016) supports a U-shaped schedule, with the peak scheduled at either the beginning or the end being optimal. To bridge this gap, in this paper, we develop a model with acclimation and heterogeneous memory and show it explains the existence of interior-peak schedules.

We characterize structural properties of the optimal schedule, which give rise to an interesting implication that whenever an interior peak is optimal, it is also optimal to introduce a "jump" or "drop" in the utility before or after the peak activity. Furthermore, we investigate the effect of the memory decay rate of the peak activity on its optimal position in the service package. We find that, counterintuitively, such an effect may be nonmonotonic; that is, as the peak activity becomes less memorable, the optimal start time of the peak activity first increases and then decreases. In addition, we examine the optimal activity selection problem. We show choosing a portfolio of highest- and lowest-utility activities, but skipping the medium-utility activities, can be optimal.

Our work may be extended along several directions. Because we focus on developing a theory of interior peaks, we assume, for simplicity of analysis, that all the activities other than the peak share the same memory decay rates. One possible direction for future research is to consider nonpeak activities belonging to two or more groups, each of which is associated with a memory decay rate. Examining the case with multiple peaks may help explain the preference for a schedule with multiple local peaks as Lawrence (2014) suggests ("wow-Wow-WOW!"). We expect that the optimal solution shares similar structural properties, and a similar dynamic algorithm may be developed based on these properties.

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Endnotes

[1] Incorporating psychological phenomena and customer satisfaction is a common approach in the service operations literature; see Chen et al. (2009), Chen and Robinson (2014), Mishra et al. (2018), and Yuan et al. (2021) for examples.

[2] See, for example, Gent and McBurney (1978) and Dalton and Wysocki (1996) for field experimental approaches to estimate the acclimation process.

[3] In practice, service designers can use questionnaires (see, e.g., Ochsner 2000) to sample customers' memory recall of various activities in a service package to (1) estimate the memory decay process and (2) determine whether memory decay is heterogeneous across activities.

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