The Impact of Various Types of Pre-Event Activities on the Departure Time Choices of Special Events Attendees

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Abstract. Special events, while fulfilling the spiritual needs of citizens, often lead to severe traffic congestion. Providing pre-event activities can effectively alleviate this issue and offer additional utility for special event attendees. However, the types of pre-event activities are diverse, necessitating an examination of the impact of different types of pre-event activities on the time choice of attendee travel. Based on the bottleneck model theory, this paper classifies pre-event activities into two categories: officially organized and spontaneously organized. It constructs utility functions for these two types of pre-event activities and obtains analytical solutions for the travel time choice problem of special event attendees under different types of pre-event activities based on equilibrium theory principles. Through numerical example analysis, we find that although pre-event activities can promote the advancement of peak periods, they cannot guarantee alleviation of traffic congestion. On the contrary, unreasonable pre-event activities may lead to further traffic congestion. This finding enhances our understanding of the role of pre-event activities and provides theoretical support for the formulation of pre-event activity plans before the implementation of special events.

Keywords: urban traffic, departure time choice, bottleneck model, special event, pre-event activities

1. Introduction

Special events are organized public or private activities, typically occurring as either one-time or periodic occasions, encompassing a variety of celebratory events, artistic performances, sports competitions, business functions, and community activities, among others [1]. Although special events can enrich citizens' lives, stimulate economic growth, spur consumption, and enhance city image, they can also bring about some negative impacts on the city during their hosting period, such as traffic congestion and shortage of parking spaces. It has been shown that special events are major sources of non-recurrent congestion, estimated to account for more than half of all congestion [2]. In order to circumvent the drawbacks, attendees are inclined to adopt more flexible schedules, such as opting for earlier departure times [3]. Individuals arriving early can derive additional utility by participating in pre-event activities, such as attending official warm-up events, or exploring neighboring shopping centers and the like. Participating in pre-event activities inherently offers additional utility to the attending attendees, whilst also adeptly

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mitigating traffic congestion caused by punctual arrivals. This, in turn, alleviates the concentration of transportation demands surrounding the venue.

Giuliano and Lu [2] has demonstrated that pre-event activities can guide participants to arrive at the event venue earlier and in a more dispersed manner. Despite the significant impact of special events on traffic congestion, the current research on this topic is relatively sparse. Kwoczek et al. [4] proposed an integrated solution for predicting and visualizing non-recurrent

traffic congestion induced by planned special events. Skrodenis [5] presented a methodology for calculating the traffic capacity of road sections during special events, taking into account their variations based on different traffic management schemes. Dai et al. [6] developed a general procedure for traffic organization management tailored for diverse special events. They proposed both static and dynamic traffic organization methods and management strategies, along with the corresponding operational steps. However, there is a relative scarcity of research concerning the impact of pre-events on special events [7][8]. Bao et al. [9] pioneered the incorporation of pre-event activities into the research of issues related to special events. This study simulated the departure time choices of attendees with varying utilities for pre-event activities. The variations in the utility of pre-event activities among attendees were manifested in the continuous distribution of sensitivity towards pre-event utility. However, the study largely concentrated on the impact of identical pre-event activities on the attendee's travel time, while overlooking the attendee's selection of diverse types of pre-event activities. To simulate the impact of the attendee's selection of different types of pre-event activities on departure times during special events, this study innovatively categorizes pre-event activities into two types: official warm-up activities organized by the event authorities, and spontaneously organized private gatherings. Furthermore, based on the distinct characteristics of these two types of pre-event activities, utility functions have been separately established for each.

Another branch of literature has focused on integrating the parking problem into the well-known bottleneck model [10]. Empirical analysis demonstrates that special events often result in corridor congestion and bottlenecks in the vicinity of the event location [11]. So far, according to the bottleneck model, a lot of research results have been derived to analyze the travel cost problem during the peak period [12][13][14].

To simulate the impact of different types of pre-event activities on the attendee's departure time choices, this paper innovatively constructs utility functions for two types of pre-event activities (officially organized and spontaneously organized by private individuals), based on bottleneck model theory. This lays the groundwork for a research paradigm examining how different types of pre-event activities influence the departure time choices of special event attendees. Building on the classical bottleneck model, this paper constructs a model of attendee's departure time choices based on pre-event activities, considering the cost of departure time for the attendees, early arrival penalty, late arrival penalty, and the utility of pre-event activities. The paper analyzes the cost composition of travel for attendees participating in different pre-event activities and determines departure time choices based on equilibrium theory. This is followed by a case study analysis, discussing the impact of pre-event activities on attendee's departure time distribution and travel costs. Ultimately, this research aims to assist large event organizers and governmental management departments in formulating reasonable pre-event activity strategies to alleviate traffic pressure and enhance economic benefits.

2. Methodology

2.1 The attendee's travel time cost

This paper assumes homogeneity among all attendees' members and employs the bottleneck model to depict the dynamic traffic congestion around large event venues or at bottleneck locations. It is posited that there exists a bottleneck at the event venue with a fixed capacity s. When the vehicle arrival rate at the bottleneck exceeds this capacity, that is, when the number of vehicles arriving per unit of time surpasses the fixed capacity, queuing occurs. Concurrently, it is considered that the bottleneck capacity is fully utilized throughout the peak period under consideration in this study.

According to Vickrey's classic bottleneck model, the total travel time $T(t)$ for attendees' departing at time t is as follows:

$$T(t) = T^f + T_q(t) \tag{1}$$

In this context, T^f represents the fixed travel time for homogeneous travelers and for ease of calculation and analysis, set $T^f = 0$. $T_q(t)$ denotes the queueing time at the bottleneck for travelers departing at time t. When the bottleneck is not fully utilized, $T_q(t) = 0$, and the travel time for attendees is $T(t) = T^f$. The expression for $T_q(t)$ is as follows:

$$T_q(t) = \frac{D(t) - s(t - t_s)}{s} \tag{2}$$

In the given context, $D(t)$ represents the cumulative number of departures at time t, while t_s refers to the departure time of the first attendees during the entire peak period. The expression for $D(t)$ is as follows:

$$D(t) = \int_{t_s}^{t} d(u)du \tag{3}$$

where $d(t)$ signifies the departure rate at time t. Further, the time $a(t)$ at which a spectator departing at time t reaches the destination can be determined as follows:

$$a(t) = t + T_q(t) \tag{4}$$

In summary, this paper constructed a travel cost function considering the utility of pre-event activities, based on the method of building the travel cost function in the classical bottleneck model by Vickrey. The travel cost for the attendees is mainly composed of three parts: time cost, early/late arrival penalty, and pre-event activity utility. When the attendee's departure at time t and arrives at the event venue at time $a(t)$, the travel cost $C(t)$ is:

$$C(t) = \begin{cases} \alpha \cdot (a(t) - t) + \beta \cdot (t^* - a(t)) - U_{pi}(t), & t_s \le t \le t_\mu \\ \alpha \cdot (a(t) - t) + \gamma \cdot (a(t) - t^*) - U_{pi}(t), & t_\mu < t \le t_e \end{cases} \tag{5}$$

where α represents the shadow price of travel time cost, β symbolizes the shadow price of early arrival penalty cost, and γ signifies the shadow price of late arrival penalty cost. t^* corresponds to the start time of the event, while t_μ represents the departure time for travelers arriving at time t^*. U_{pi} denotes the utility of the attendees participating in the i th type of pre-event activity. In this paper, we assume that each attendee's member begins to participate in pre-event activities immediately upon arriving at the venue, and that each attendee's member will only participate in one pre-event activity, ruling out the possibility of participating in multiple pre-event activities.

2.2 Pre-event activity utility

This paper considers two types of pre-event activities: official warm-up activities and private entertainment gatherings.

Organized warm-up activities refer to activities related to the theme of the special event organized by the event host, social organizations, etc., such as meet and greets, support activities, and peripheral sales. These pre-event activities usually have fixed start and end times and are usually held in the venue of the major event or surrounding shopping malls on the eve of the major event. The utility of warm-up activities generally shows a positive correlation with the time spent participating in the warm-up activities.

Private gatherings refer to private gathering decided upon by the attendees, such as shopping and afternoon tea around the event venue. The start time of these pre-event activities is determined by the attendees themselves. Due to the uncertainty of the time allocated to private gatherings, theoretically, the duration of a private gathering can be quite long, and its utility function is mainly composed of the satisfaction and fatigue the participants feel. Hence, although the satisfaction derived from the private gathering is positively correlated with the duration of the gathering, it also exhibits characteristics of diminishing marginal utility as the gathering time increases. It is also worth noting that as the duration of the private gathering increases, the fatigue felt by the participants of the gathering also positively correlates with the duration of the gathering and exhibits characteristics of increasing marginal utility as the gathering time increases.

Considering the purpose and nature of the warm-up activities, we hypothesize that the attendees is unable to engage in pre-event activities during the period between the end of the warm-up activities and the start of the main event. Based on the characteristic that the utility of warm-up activities generally shows a positive correlation with the time spent participating in them, and for the sake of facilitating further calculations, we may assume the marginal utility of participating in warm-up activities for a time Δt as a constant M, where $M > 0$. Therefore, the marginal utility of warm-up activities, denoted as $MU_{p1}(\Delta t)$, for a traveler who participates for a time Δt can be expressed as:

$$MU_{p1}(\Delta t) = \begin{cases} M & , 0 < \Delta t < t_2 - t_1 \\ 0 & , else \end{cases} \tag{6}$$

where t_1 denotes the start time of the organized warm-up activities, and t_2 signifies the end time of these activities, $\Delta t = t_2 - a(t)$. Furthermore, the utility function of the organized warm-up activities, denoted as $U_{p1}(t)$, is expressed as:

$$U_{p1}(t) = \begin{cases} M_1 & , a(t) \leq t_1 \\ M\big(t_2 - a(t)\big), & t_1 < a(t) < t_2 \\ 0 & , a(t) \geq t_2 \end{cases} \tag{7}$$

where $M_1 = M(t_2 - t_1)$. Given that the utility function for private gathering is primarily composed of the satisfaction and fatigue experienced by participants, we initially construct its marginal utility function. To facilitate computation and maintain the marginal utility properties of satisfaction and fatigue, we employ a linear function to represent the marginal utility of private gathering. The marginal utility for a private gathering participating for a duration of Δt, denoted as $MU_{p2}(\Delta t)$, can be expressed as:

$$MU_{p2}(\Delta t) = MU_{q1}(\Delta t) - MU_{q2}(\Delta t) \tag{8}$$

$$MU_{q1}(\Delta t) = \begin{cases} -P_1 \cdot \Delta t + P_2, 0 < \Delta t \leq \dfrac{P_2}{P_1} \\ 0 \quad\quad , else \end{cases} \tag{9}$$

$$MU_{q2}(\Delta t) = Q \cdot \Delta t \tag{10}$$

where $MU_{q1}(\Delta t)$ and $MU_{q2}(\Delta t)$ denote the marginal utility functions of satisfaction and fatigue, respectively, corresponding to the party duration of Δt, with $\Delta t = t_2 - a(t)$. The parameters P_1, P_2, and Q are positive numbers with the value of $\frac{P_2}{P_1}$ required to be sufficiently large. Furthermore, to reflect a higher level of preparation for official pre-party activities compared to private gathering, we propose that $P_2 \leq M$. This suggests that the utility generated during the same period from the pre-party activities is never lower than that from private gathering. Additionally, based on the condition that $U_{p2}(\Delta t) = 0$ when $\Delta t = 0$, we can derive the utility function of private gathering, $U_{p2}(\Delta t)$, as:

$$U_{p2}(t) = (\delta \Delta t + \varepsilon)\Delta t \tag{11}$$

where $\delta = \frac{Q-P_1}{2}$, $\varepsilon = P_2$. The schematic diagram showing the change in utility acquired by attendees of warm-up activities in relation to arrival time $a(t)$ is depicted in Figure 1. Similarly, Figure 1 presents a schematic diagram illustrating the change in utility gained by attendees of private gathering as a function of the duration of stay.

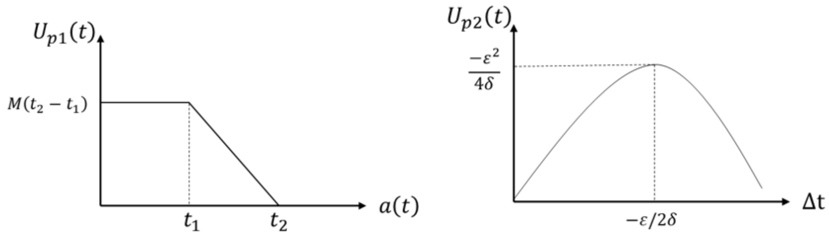

Figure 1. Utility Function of Official Warm-up Activities and Private Gathering Activities

2.3 Model computation

Based on the utility of pre-event activities derived from Eq. (7) and Eq. (11), we can categorize the attendees participating in pre-event activities into three distinct types: attendees of spontaneously organized private gatherings, attendees of official warm-up activities, and those who do not participate in any activities. Moreover, given that each attendee participates in at most one pre-event activity, attendees of warm-up activities can be further bifurcated into two subcategories: those who arrive before the start of the warm-up activities and those who arrive during the warm-up activities.

We surmise that attendees will always choose the type of pre-event activities that yield greater utility upon arriving near the event venue[3]. Therefore, we can ascertain the selection of pre-event activities by attendees during the peak period by analyzing the utility functions of the two types of pre-event activities, as illustrated in Figure 2.

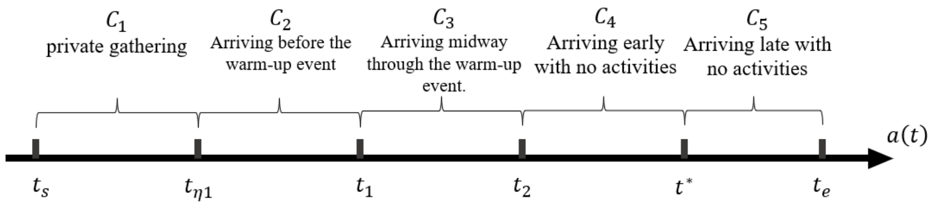

Figure 2. The Relationship Between Attendee Arrival Time and Pre-Event Activity Patterns

The parameters t_s, t_e, and $t_{\eta 1}$ are endogenous, whereas the parameters t^*, t_1, and t_2 are exogenous, each representing the junction points of different periods.

In equilibrium state, the travel costs of each attendee are equal, and no one can reduce their own travel costs by unilaterally changing their departure time. Consequently, we can obtain the first-order equilibrium condition:

$$\frac{d\big(C(t)\big)}{dt} = \begin{cases} \alpha(a'(t)-1) - \beta a'(t) - U'_{pi}(t) = 0, & t_s \le t \le t_\mu \\ \alpha(a'(t)-1) + \gamma a'(t) - U'_{pi}(t) = 0, & t_\mu < t \le t_e \end{cases} \tag{12}$$

Based on the first-order equilibrium condition, and given that $a(t_s) = t_s, a(t_e) = t_e$ at the start and end of the peak, the expression for the arrival time function $a(t)$ of the attendees departing at time t under equilibrium can be derived as follows:

$$a(t) = \begin{cases} \dfrac{1}{2\delta}\left(\mu_1 + \sqrt{{\mu_1}^2 - 4\delta\big(t\alpha + t_s(-\beta + 2t_2\delta - t_s\delta + \varepsilon)\big)}\right), & t_s < a(t) < t_{\eta 1} \\ \dfrac{t\alpha}{\alpha - \beta} + c_{11} & , t_{\eta 1} < a(t) < t_1 \\ \dfrac{t\alpha}{M + \alpha - \beta} + c_{12} & , t_1 < a(t) < t_2 \\ \dfrac{t\alpha}{\alpha - \beta} + c_3 & , t_2 < a(t) < t^* \\ \dfrac{t\alpha}{\alpha + \gamma} + \dfrac{\gamma(N + st_s)}{s(\alpha + \gamma)} & , t^* < a(t) < t_e \end{cases} \tag{13}$$

where $\mu_1 = \alpha - \beta + 2t^*\delta + \varepsilon$. Furthermore, c_{11}, c_{12}, and c_3 all represent parameters that satisfy the boundary conditions. Given that the bottleneck is fully utilized during peak times, the arrival time function $a(t)$ for an attendee departing at time t is a continuous function. Further resolution can yield:

$$c_{11} = \frac{1}{s(\alpha - \beta)}\big(Ms(t_2 - t_1) + (N + st_s)\gamma - st^*(\beta + \gamma)\big) \tag{14}$$

$$c_{12} = \frac{1}{s(M + \alpha - \beta)}\big(Mst_2 + (N + st_s)\gamma - st^*(\beta + \gamma)\big) \tag{15}$$

$$c_3 = \frac{1}{(\alpha - \beta)}\left(\gamma\left(t_s + \frac{N}{s}\right) - t^*(\beta + \gamma)\right) \tag{16}$$

In accordance with the properties of the bottleneck model, the bottleneck capacity is fully utilized during peak periods, hence $t_e = \frac{N}{s} + t_s$. Further resolution can yield:

$$t_s = \frac{-s\mu_2 + \sqrt{s\left(-4N\gamma\delta + s\big((\beta+\gamma)(\mu_2 + 4t^*\delta - 2t_2\delta - \varepsilon) + \varepsilon^2\big)\right)}}{2s\delta} \tag{17}$$

where $\mu_2 = \beta + \gamma - 2t_2\delta - \varepsilon$. In summary, we have obtained the analytical solution of $a(t)$. By integrating Eq. (2) and Eq. (4), we can derive the departure rates $D(t)$ during peak periods in equilibrium state:

$$D(t) = \begin{cases} \frac{s}{2\delta}\left(\alpha - \mu_3 + \sqrt{\alpha^2 + \mu_3{}^2 + 2\alpha(-\beta - 2t\delta + 2t_2\delta + \varepsilon)}\right), t_s < a(t) < t_{\eta 1} \\ \frac{N\gamma + s\big(M(t_2 - t_1) + t\alpha - t^*(\beta+\gamma) + t_s(\beta+\gamma-\alpha)\big)}{(\alpha-\beta)}, t_{\eta 1} < a(t) < t_1 \\ \frac{N\gamma + s\big(M(t_2 - t_s) + t\alpha - t^*(\beta+\gamma) + t_s(\beta+\gamma-\alpha)\big)}{(M+\alpha-\beta)}, t_1 < a(t) < t_2 \\ \frac{N\gamma + s\big(t\alpha - t^*(\beta+\gamma) + t_s(\beta+\gamma-\alpha)\big)}{(\alpha-\beta)}, t_2 < a(t) < t^* \\ \frac{\gamma N + s(t - t_s)\alpha}{\alpha+\gamma}, t^* < a(t) < t_e \end{cases} \tag{18}$$

where $\mu_3 = \beta - 2t_2\delta + 2t_s\delta - \varepsilon$. In the equilibrium state, each travelers incurs an equal travel cost C^*:

$$C^* = \frac{\gamma}{2s\delta}\left(2N\delta + \sqrt{s(-4N\gamma\delta + s(\beta+\gamma-\varepsilon)^2)} - s(\beta+\gamma-\varepsilon)\right) \tag{19}$$

3. Numerical Studies

In conjunction with the model constructed previously, this chapter will illustrate the issue of special event attendees travel time selection based on pre-event activities through numerical examples. The assignment of values for each parameter is as shown in Table 1.

Table 1 Parameter Configuration

t^*	α	β	γ	N	s	M	δ	ε	t_1	t_2
19	0.9	0.5	1.5	5000	100	0.5	-0.1	0.45	18.75	18.92

Arrival time function $a(t)$ of the attendees departing at time t and the cumulative departures and arrivals are given in Figure 3 and Figure 4.

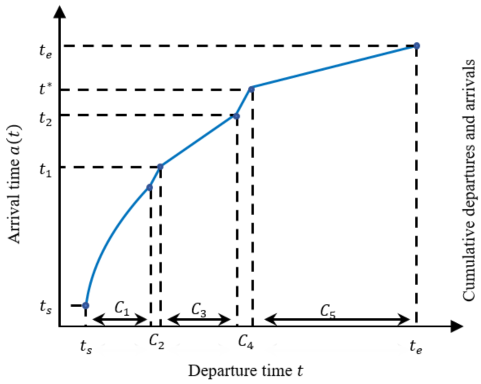

Figure 3. Arrival Time Function

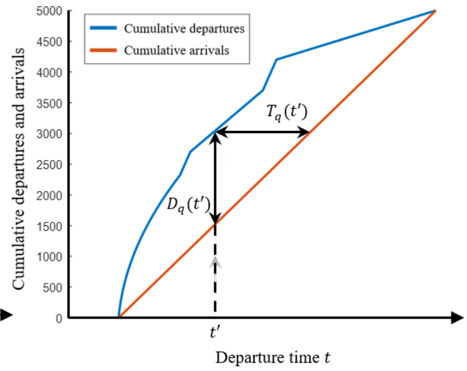

Figure 4. Cumulative Departures and Arrivals

Variation of queueing time with departure time is given in Figure 5.

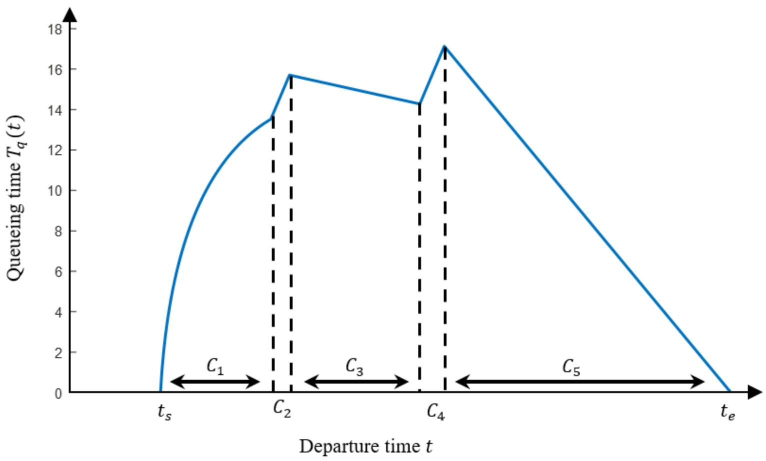

Figure 5. Queueing Time Function

It can be observed that the presence of pre-event activities significantly affects the queuing time of travelers, and this impact is not necessarily positive. If the pre-event activities are set to be too "attractive", it may cause more serious queuing phenomena for participation.

The effectiveness of the model is indirectly validated by relevant typical instances of traffic congestion during special events. Taking the analysis of congestion data for mainland concerts using Amap as an example [15], the estimated congestion delay index for Wang Feng's concert at the Bird's Nest reached 3.4, while Zhang Jie's concert at the Liaoning Sports Stadium had a congestion index of 2.8. Unlike the Bird's Nest Stadium in Beijing, which mainly alleviates traffic congestion through traffic control measures, the concert at the Liaoning Sports Stadium adopted pre-event activities, which to some extent supports the conclusions of this study. In the future, further exploration can be conducted through more empirical data.

4. Conclusions

In the research process, we construct utility functions for different pre-event activities and simulate the attendee's choice of different types of pre-event activities based on the bottleneck model. Through numerical simulation, this paper explores the attendee's travel behavior in the equilibrium state when there are various pre-event activities. By analyzing the results of numerical simulation, we find that if the commercial area or other activity facilities around the event venue can provide activities or venues for the attendee before the start of special events, it attracts some attendee with greater time flexibility to set off in advance. These attendees participate in pre-event activities around the venue before the commencement of the special event, enjoying the benefits of pre-event activities. However, it should be noted that the different nature of pre-event activities does not necessarily have a completely positive impact on the total travel time. To participate in pre-event activities for additional utility, travelers may face more severe traffic problems.

In future research, we will further explore how pre-event activities influence the travel behavior choices of the attendee, and how to arrange pre-event activities to alleviate traffic congestion issues while obtaining additional benefits. In addition, in future work, we will validate the conclusions through experimental data from specific real-life scenarios.

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