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Evaluating Users' Benefits from a Crowd Management System in a Smart City Project

Wenjing YANG
Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong
(email: *w.j.yang@connect.polyu.hk*)
Patrick T. I. LAM
Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong
(email: *bsplam@polyu.edu.hk*)
Meng, NI
Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong
(email: *meng.ni@polyu.edu.hk*)

Abstract

Information and Communication Technologies are deployed in smart cities to enhance efficiency, convenience and safety. However, the benefits are usually intangible since the services do not carry a market price. This paper presents a research on a crowd management system as a smart city project using the Contingent Valuation (CV) method to estimate the users' benefits. A marathon which took place in Hong Kong was adopted as a pilot study to analyze the application of CV in a major event during which video analytic equipment was deployed to feed real time data into an information dissemination system for dissipating crowd efficiently from the venue. The Willingness-to-Pay (WTP) is derived from an on-the-spot survey with the non-parametric method, which is reflective of the non-market benefits as perceived by users of the CM system.

Keywords: Smart city, Crowd Management (CM) system, Willingness-to-Pay (WTP), Information Communication Technology (ICT), Contingent Valuation (CV) method

1. Introduction

Smart city projects aim at making a city greener and more people-friendly (Cocchia, 2014). With the advent of information and communication technologies (ICT), it is hoped that governance and socio-economic vibrancy would be enhanced through such smart city projects (Neirotti *et al.*, 2014). In the arena of public safety, crowd management is an important function of smart cities (Kumar *et al.*, 2018). In large-scale events, the usual route may be changed temporarily, and people cannot make efficient route planning without updated information. Overcrowding and mismanagement of mass gatherings have led to a number of accidents and catastrophes. A wrong route choice may lead to waste of time, bad emotion and unruly behaviors, such as climbing to surpass guardrails (as shown in Fig.1), which are very dangerous from the perspective of public safety. Stampedes may occur, leading to injuries, which are sometimes life-threatening. Close monitoring of crowd movements and density by event organizers and security departments in real time is necessary to ensure the participants' safety. Because of the complexities of the scene and dynamic crowd formation and movement, effective crowd management ensuring participants' safety and convenience is one of the most vital tasks and biggest challenges to the responsible public agencies during large mass gatherings.

Figure 1: Crowds surmounting guardrails after a firework display in Hong Kong.

Security aside, many factors affect a decision on the choice of alternative transportation modes for the participants when they leave a large-scale event venue. A Crowd Management (CM) system is a comprehensive and precise decision support tool for detecting and tracking participants' number and motion information in real-time, often giving directions on possible routes or nearby escape alternatives. A fully integrated CM system generates different alternatives to enhance interoperability for the users (event organizers, safety and security forces and the public) to take appropriate actions for monitoring and marshalling mass gatherings. Efficient CM systems using modern technology (such as GPS) with smartphones can enhance the accuracy of detection and tracking and provide location-based services to dynamic pedestrians. The remotely-sensed data and indicators representing dynamic effects caused by pedestrian congestion and movement are transmitted to the App installed in the users' smart phones or monitoring facilities. As a typical smart city project, new technologies such as CCTV, global positioning system (GPS) technologies, Virtual Reality (VR), Radio-frequency identification (RFID), and other ICT installations are applied in dealing with real life overcrowding problems.

The design and implementation of a state-of-art CM system pave a new way for executing an emergency plan automatically and intelligently. The use of video analytic software, coupled with recognition of digital images captured with high-resolution CCTV, is one such technique. Besides, with recent novel VR applications in a CM system for emergency response, it proves to be valuable in dealing with egress design, selection and optimization of evacuation routes in case of emergency and could help with the simulation of human flow. In addition, the upcoming implementation and application of 5th generation wireless technology could make the real-time movement tracking a reality. With the active search for solutions by many countries, CM systems become increasingly popular in the smart city arena. The popular utilization of CM systems and the related ICTs have created a need for evaluating the non-market benefits of CM systems to see whether the related technologies are worth the spending of city resources.

2. Literature review

Smart cities provide convenient facilities and intelligent infrastructure to residents. The innovation of the ICT gives rise to a series of new functionality in cities to make them smarter (Yeh, 2017). Apart from a technical feasibility study, the launch of a smart city project needs economic justifications. An economic assessment framework requires that various costs and benefits should be reflected in the overall analysis. The intangible benefits, such as reductions in carbon emissions, noise, and time saving, should be taken into consideration for realistic decision-making. In the crowd management scenario of this research, the non-market benefits of users are based on their perception which is quantified in monetary terms. Cost-Benefit Analysis (CBA) is a systematic decision-making approach, involving an evaluation of the benefits and costs from the economic and social perspectives of proposed projects (Boardman *et al.*, 2017). It is widely used to assist the decision-makers on transportation (Kockelman, 2003) and environmental projects (Haab and McConnell, 2002) in the US and Europe. The theoretical approaches of CBA for estimating benefits can be categorized into two main types of capturing mechanism: Revealed Preference and Stated Preference. Most smart city projects involve non-market goods and services. Therefore, scenarios of smart city projects are not suitable for the Revealed Preference (which relies on price) approach in welfare economics due to observation difficulties. Instead, the perception of benefits by the public is quantifiable via a Stated Preference approach (Höjer *et al.*, 2008). There are two measures representing monetary values of a benefit or harm to an individual: the maximum Willingness to Pay (WTP) for a welfare improvement or the minimum Willingness to Accept (WTA) as compensation for welfare loss (Hammitt, 2015). The study of WTP and WTA about equivalent gains or loss of the users entails separate questions being asked for analyzing the respondents' preference based on a specific hypothetical scene and accurate risk descriptions.

Contingent Valuation (CV) is a well-developed Stated Preference technique to derive people's WTP (and WTA) for the changes of quantities or qualities of goods or amenities (Hanemann, 1994). This economic valuation method utilizes surveys to estimate the benefits of a composite commodity (Milon, 1989). It implies that the respondents monetize the value of obtaining or losing the benefits themselves directly. With the options of the different questioning approaches (such as single-bounded and double- bounded), the questionnaire of CV usually poses a question asking the respondents: *are you willing to pay (or willing to accept) $X* according to a hypothetical and clearly described scenario (Bateman *et al.*, 2002). Then the calculation makes use of the response reacting to this hypothetical question (Hanemann, 1984). Through collecting and processing perception data, CV is particularly effective to estimate non-market benefits (Milon, 1989), especially in the provision of public goods and services, e.g. time-saving, convenience, and environmental protection.

The CM system can increase the mobile efficiency of human and road traffic, and safeguard people interacting in crowds in major gathering scenarios such as festive events or galas. CM systems are applied in large-scale events in many countries as smart city initiatives, especially with the utilization of fast developing ICT technologies. Being based on Internet of Things (IoT) configuration, the development and application of network virtualization can improve the efficiency of crowd management, such as in mega shopping centers and entertainment complexes, large-scale sports events and celebrations, and large transportation terminals. Most of traditional large-scale gatherings rely on professional observations and intuition of duty staff (e.g., police) when involving crowds with great densities. Practical guidelines advocate planning, risk assessment, putting precautions in place, setting up emergency plans and procedures, communication, monitoring crowds and post-event reviews. Monitoring includes the estimation of crowd sizes and a variety of approaches have been used, including the use of hand counters, distribution of wristbands, turnstiles at entry points and sampling in a small area, etc. All these measures entail substantial manpower deployment. Fruitful crowd management research with various modeling approaches has unraveled the causes of crowd disasters happening during massive mobility events.

Since smart city projects often provide intangible benefits due to the non-market services, decision makers often find it difficult to carry out investment appraisal and compare between alternatives. This study focuses on evaluating the users' benefits (through a measure of total WTP) arising from the deployment of a CM system in a large-scale marathon event in Hong Kong. A survey was conducted after a large-scale gathering event, which is a proof-of-concept case to test the technical feasibility. During the study of a CM deployment in a district marathon event, the time limitation significantly presented challenges in interviewing a departing crowd from the scene. The single bounded approach asking one value instead of increasing or decreasing values based on an initial answer was considered to have higher operability and hence more suitable. As a pilot study, the limitations and areas for improvement in future applications are discussed.

3. Methodology

3.1. Survey

Hong Kong was chosen as the survey destination since plans were unfolded by the government to build a pilot smart city. The Hong Kong Government has developed a smart CM system via an App for installation in smart phones (synchronized with electronic signboards erected at the exit locations) by participants in this Marathon event, which provides real-time information on exit transport modes and expected queuing time. Besides, Hong Kong has a population of approximately 7.39 million with the density of 6,830 people per square kilometer in 2017 (GovHK, 2018), and many large-scale events are being held every year. The orderly dismissal of the large numbers of participants is a critical task in crowd management. The district marathon was held on a Sunday morning in January 2017 in Hong Kong, and the number of participants was more than 15,000. The total length of runway was 32 km. As a proof-of-concept exercise of smart city, this App development (and the electronic signboards), as well as video analytic equipment, was out-sourced by the government to a private sector operator. Installation of the App was free of charge by participating users at this phase and the near future.

The CM system in this study comprised of video analytic equipment, a software estimating the queuing time of each transport mode and disseminating this information to the participants with a smart phone App (and enroute electronic signboards). This system was applied by the event organizers in the management of the crowds to enable safe and efficient departure of participants and their supporters from the district marathon end-point venue with the aid of ICT. The users benefitted in having real time information to help them select means of public transport for their return journeys. The CM system was also used by the duty staff to detect the crowd flow and identify unforeseen circumstances with the CCTV surveillance cameras to provide nearly real-time information. Being a proof-of-concept exercise, no staff manpower of the monitoring and emergency services was reduced, and fortunately no incident occurred in this particular event.

This study focused on the intangible benefits of facilitating the event participants in selecting means of public transport for their return journeys, through the estimation of the individuals' WTP via a questionnaire administered face-to-face. The survey was conducted among the participants and their relatives/friends who were leaving the scene, having taken a rest after the marathon, at the queues formed at a coach terminal, a mini-bus stop and a nearby public ferry pier. The questions were written on a leaflet and spoken in Chinese by a trained survey team of 4 members. The predominantly Chinese participants were selected by a random sampling approach. The questionnaire was designed in a single-bounded format, and each respondent was briefed on the functions of the App downloaded in the smart phone held by the survey team members. The interviewers demonstrated the screens showing the functions and display information using their own smartphones.

A critical issue for the survey is the setting of suitable bid values to represent the possible WTP. Thus, a pilot test was conducted before the formal survey was carried out. Given that most smart phone Apps were being transacted at US$1 (approx. HK$7.8, which is the prevailing exchange rate) each around the time of the study, the initial bid levels were set at HK$2, 5 and 10 on alternate questionnaires. Twenty-three face-to-face pilot interviews were first conducted in the verification of suitable bid values, and the results are depicted in Table 1 as follows:

Table 1: The bid value profile in the pilot test

Bid (HK$)	No. of Answering *No*	No. of Answering *Yes*	Total
2	4	5	9
5	4	3	7
10	3	4	7
Total	11	12	23

From Table 1, the proportions of responses on the 3 proposed values were all around 50%, which sounds suitable for eliciting responses. Thus, the bid levels of the WTP question were set as HK$2, 5, and 10 in the survey of the CM system. The respondent was asked whether he or she was willing to pay a given amount (HK$2, 5 or 10) in a form of a hypothetical payment for downloading the App following with the fictitious payment methods depicted. The response would represent the value of the information provided by the CM system to the users. Apart from the WTP question, the questionnaire also asked each respondent to rank the usefulness of the information provided by the app according to an increasing Likert Scale of 0 to 10. A team of 4 interviewers worked in this survey, each being responsible for a fixed value as abovementioned, with a floating member to work on 3 values. All members targeted at different queues at various times to ensure randomness. The interviewing had to be completed in about 1-hour after the marathon running finished. Due to the time constraint and the number of interviewers allowable by the event organizer versus the large number of participants, the valid sample size achieved was 174. A number of respondents refused to answer the questions and they were not counted in the effective sample size.

3.2. Economic Valuation

CV with the option of single-bounded questioning approach is adopted for collecting and processing data of the users' benefits, utilizing non-parametric analysis to estimate the benefits, with the advantage of no explicit assumption of population distribution to draw the sample size. The anonymous questionnaire has two sections, with Section A on simple demographics, e.g. gender, age, etc. Section B asked the respondents if they had ever paid for downloading Apps in their smart phones. Using the single-bounded approach, the next standard question was '*are you willing to pay $X*' (*$X* being the bid value) *to download the app given its stated functions'*. The respondents just answered *Yes* or *No*. The estimation of WTP was based on the binary data obtained from the single-bounded questionnaire. It was made clear to the respondents that the App was provided free of charge to all registered participants and the value which they were asked about was purely hypothetical. The last question requested the respondents to rate the usefulness of the App based on a 0-10 Likert scale.

With the advantage of nil assumption about data distribution, the straightforward method of non-parametric method is less restrictive than the parametric method. The non-parametric method has significant advantages in that it is simple to use and there is no need for any distribution assumption (Kristrom, 1990). An empirical estimate of the survivor function ($\hat{T}$, the probability of observing a WTP greater than a particular value) at each of the offer value (V_j) can be calculated as (Bateman *et al.*, 2002): -

$$\hat{T}\left(V_j\right) = n_j/N_j \quad ; \; j = 0 \; to \; J \tag{3.1}$$

where the total number of the samples is represented by *N*, the sub-sample size related to V_j (the bid level) is denoted as N_j, and n_{jj} is the number of respondents in the sample with a WTP greater than V_j (answering 'Yes' to the WTP of V_j). Given the fact that every effective respondent was willing to pay a non-negative amount for the non-market good, set $\hat{T}\ (V_0) = 1$.

Since no assumption needs to be made on probability distribution, the mean WTP (*M*) can be calculated as the area under the step function graph according to the following formula (Bateman *et al.*, 2002):

$$M = \sum_{j=1}^{J} \hat{T}\left(V_j\right)[V_j - V_{j-1}] \tag{3.2}$$

In the above formula, *M* is the mean WTP calculated as a distribution-free estimate, and the median is the interpolated offer value having 0.5 as $\hat{T}\left(V_j\right)$.

4. Results

The CM system was deployed in the form of a pre-downloaded App (and the enroute electronic signboards) for the first time in Hong Kong. Although the organizer made prior promotion efforts, a considerable number of participants were still not aware of the availability of the system. Hence, the interviewers explained the functions of this system with smart phones to the respondents on the spot before eliciting their answers to the questionnaire. However, the longer time taken to brief the interviewees about the apps functions resulted in a smaller sample size (174) being achieved in the event than expected. As shown in Table 3, 81.6% respondents are runners with the age ranging from 16 to 65. 37.4% respondents had the habit to download and install priced Apps online. Besides, results of the survey indicated that the number of respondents being aware of the Apps themselves was only 5 (2.87%), and the number of respondents noticing the electronic signboard information themselves was 18 (10.34%). The respondents' demographic profile and the co-variate data are shown in Table 2. Within the total number of valid samples (174), the number of respondents who agreed to a given value (WTP) was 45 (25.86%) (see Table 4). All computations were performed using the SPSS statistical package.

Table 2. Profile of the Co-variates

Variable	Description	Mean	S. D.
Gender	1 = *Male*; 2 = *Female.*	1.33	0.473
Age	1 = *Below 15;* 2 = *16~25;* 3 = *26~35;* 4 = *36~45;* 5 = *46~55;* 6 = *56~65;* 7 = *Above 66.*	3.27	1.081
Runner or not	1 = *Yes*; 0 = *No* & *Not sure.*	0.82	0.389

Used App (score only if used)	0 = *Not useful at all*; to 10 = *Extremely useful*.	0.13	0.804
Noticed electronic signboard (score only if noticed)	0 = *Not useful at all*; to 10 = *Extremely useful*.	0.58	1.875
Online payment habit	1 = *Yes*; 0 = *No & I have no idea*.	0.37	0.485
Valid Sample Size		174	

Table 3. Demographics

Variable	Description	Frequency	Percent
Gender	*Male*	116	66.7
	Female	58	33.3
Age	*Below 15*	-	-
	16~25	48	27.6
	26~35	63	36.2
	36~45	35	20.1
	46~55	24	13.8
	56~65	4	2.3
	Above 66	-	-
Runner or not	*Yes*	142	81.6
	No & Not sure	32	18.4
Online payment habit	*Yes*	65	37.4
	No & I have no idea	109	62.6

Table 4. The elicitation results

Proposed Bid Level V_j (HK$)	No. in sub-sample (N_j)	No. of answering *Yes* (n_j)	Estimate of survivor function ($\widehat{T}$)
2	43	16	0.372
5	75	22	0.293
10	56	7	0.125
Total	174	45	0.259

From the non-parametric method (Equation 3.1, 3.2), the mean WTP is HK$ 2.25, and the total users' benefit is estimated as HK$ 33,750 based on 15,000 participants in the event. This monetized value represents the estimated benefits of time saved and convenience brought to the participants by the CM system (App and the electronic signboard) when they decided on the mode of transport (mini-bus, taxi or ferry) to leave the event venue.

5. Analysis and further research

In the survey of this study, using a hard copy questionnaire would be difficult to obtain a satisfactory return rate when the participants were leaving the venue after a single morning run session, and the organizer limited the number of interviewers to 4, which was pre-approved. Despite the above setback, the survey sample size 174 was completed within one morning in this face-to-face survey. The status of the scene was not under control of the interviewers, and dozens of interviewees refused to answer the questionnaire. A mitigating factor is that face-to face interviews are considered as the "superior method that yields better results" for surveys (Bradburn, 1983). Thus, despite the set-back, the estimation of the intangible benefits has yielded good indications for future research.

Besides, this study focused on users' benefits arising from the App and electronic signboards. For a full estimate of the benefits of the CM system, it should include the reduction in manpower deployment on the part of the organizer when the system is put into repeated uses. However, for this study, the organizers, the police department and the fire services department had not reduced their manpower since this was the first trial event using the system. By attending the post-event debriefing, it was known that the number of minor injuries sustained and treated on the spot was not different from similar events. Hence, these aspects of potential benefits were not captured in this study.

On the costing side, the project cost was funded by the Hong Kong Government and it included the App development cost, the rental and installation cost of IoT and camera devices, power and communication network costs and the cost for customizing specific video analytic features for individual events. Since costing is not the focus of this proof-of-concept trial event, the data is not reported here. It is known that the CM system would be deployed in other events as necessary, when scaling up may take place, say, in a city-wide marathon.

Last but not least, the participants' awareness of the App helping them to leave the venue would be improved if such applications are more commonly deployed in Hong Kong events. Payment for smart phone Apps may also become a more habitual behavior as time goes on. These and other covariates (e.g., demographics) may affect their WTP values. These are good topics for further research.

6. Conclusion

Through smart city projects, people enjoy a more convenient life with manpower reduction, energy conservation, and environmental friendliness, contributing towards the achievement of sustainable urban development. CM systems enhance the safety and convenience of citizens and alleviate the traffic congestion when transport needs heighten in a short period. This study presents a study about a CM system undergoing proof-of-concept testing in Hong Kong, as one of the smart city initiatives, using a Stated Preference approach with the application of CV method.

In this research, the non-parametric evaluation approach was demonstrated to assess the intangible of the CM system deployed in a pilot smart city project. The CV method is used for the first time in an event involving crowds of people (a district marathon) in Hong Kong. Useful experience for carrying out cost-benefit studies of smart city projects has been gathered from this study. The estimation of users' benefits from the CM system has been revealed. Other benefits of CM systems would accrue to the event organizers, but these issues lie beyond the scope of this investigation due to the initial stage of deployment of the system in Hong Kong. The workable approach depicted in this paper can be scaled up for application in other smart city projects which have the characteristic feature of non-market services being offered to citizens.

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