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Investigating the Usage of IoT-Based Smart Parking Services in the Borough of Westminster

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ABSTRACT

Smart parking schemes cannot succeed without the engagement and support of the drivers who may benefit from their use. This study investigates engagement with a smart parking service in the London borough of Westminster. Factors likely to influence the use of smart parking services were identified from a literature review and incorporated into an explanatory model comprising 9 factors connected by 16 hypotheses. To test the model, residents of Westminster and visitors to the area were surveyed, resulting in a total of 212 valid responses. The responses were used to test a structural equation model using confirmatory factor analysis. The results of the analysis indicated that awareness of the scheme, perceived ease of use, perceived usefulness, cost saving, perceived privacy, and perceived security all had a direct impact on usage, with awareness being the most influential factor. The results also highlighted the fact that, despite efforts by Westminster Council to publicise the scheme, 74% of respondents had little awareness of it, suggesting the need for improved publicity.

KEYWORDS

Internet of Things, Smart City, Smart Parking, Usage, User Perception

1. INTRODUCTION

Despite its many advantages, continuous urbanisation has brought a wide range of problems, many of which are associated with rapid growth in car use. According to the Texas A&M Transportation Institute for example, in 2011 people living in US cities endured 5.5 billion hours of traffic delay, resulting in the use of an additional 2.9 billion gallons of fuel costing approximately \$121 billion and causing the emission of 56 billion lbs of CO₂ (Schrang *et al*, 2012). These figures are approximately five times higher than corresponding statistics from 1982. Such problems are not limited to the USA; in 2012, a report by Christidis and Rivas estimated the annual cost of traffic congestion in the EU to be around €111 billion (approximately 1% of the EU's total GDP).

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The problems associated with congestion do not just affect other drivers. Users of public transport are subject to the delays caused by traffic jams; and cyclists, pedestrians and residents are all affected by noise and pollution (Department for Business, Innovation and Skills, 2013).

One significant factor that contributes to congestion is limited parking. For example, in an analysis of data gathered from studies of cities around the world between 1927 and 2001, Shoup (2006) found that most of the studies reported that drivers searching for a parking space spent over 6 minutes ‘cruising’. Inexperienced drivers and visitors to a city are likely to take even longer (Teodorović & Lučić, 2006), with drivers surveyed in Frankfurt in 1992 reporting cruising times of over an hour (Axhausen *et al*, 1994). Such is the negative impact of seeking for free parking spaces that, in some cities, a driver doing so is referred to as a “traffic-parasite” (Giuffrè & Siniscalchi, 2012).

In many city centres, land is at a premium, so increasing the number of available parking spaces is not always an option. Smart Parking opens up possibilities for the better management of existing parking, allowing spaces to be found more quickly and filled more effectively. However, although many technologies can contribute to such schemes, they cannot succeed without the engagement of the drivers who may benefit from them.

This paper explores which factors have an impact on the engagement of drivers with Smart Parking services, and which may affect the use of on-street parking. To do so, it draws on the experiences of users of an innovative Smart Parking initiative that was introduced by the London Borough of Westminster in 2014. The research reported on here seeks to increase understanding of how new technologies associated with a Smart Parking scheme are perceived; and to explore and analyse factors that might influence the use of such a scheme. To do so, it draws on both technology acceptance theories and social influence theories to incorporate influencing factors into a predictive exploratory model.

The remainder of the paper is structured as follows. Section 2 provides a review of relevant existing literature on Smart Cities and Smart Parking; Section 3 describes our proposed theoretical explanatory model; this is followed by Section 4 that describes the research methodology, including data collection and analysis. The results of the study are presented in Section 5, including confirmation of the explanatory model and Section 6 discusses these in light of the existing literature. Finally, Section 7 concludes the paper.

2. LITERATURE REVIEW

2.1 Smart Cities

“Smart cities” have been defined in a variety of ways by different authors (e.g. Allwinkle & Cruickshank, 2011; Nam & Pardo, 2011; Chourabi *et al*, 2012, Peng, Nunes & Zheng, 2017). What links the definitions though, is a focus on the possibilities raised by the ability to connect a growing range of technologies (e.g. sensors, Internet of Things, cloud computing, big data analytics, and mobile devices). As a result, Smart City literature tends to emphasise the technical and engineering dimensions, such as IoT architecture and wireless sensor networks (Gope & Hwang, 2015; Minoli *et al*, 2017), Smart City testbeds and prototype design (Cardone *et al*, 2014), simulation models (Yamagata & Seya, 2013), and big data analytic tools and algorithms (Qiu *et al*, 2017).

However, the success of Smart Cities does not rely solely on technological factors: consideration of the city’s population and of decisions relating to its well-being, is essential. Data generated, processed and analysed by Smart City technologies should be used to inform decisions relevant to the running of a city. The shared data is both localised and up-to-date, and has the potential to improve decision-making relevant to transport, healthcare, and education, leading to a better quality of life for citizens of the smart city through enhancement of key infrastructures, utilities and services (Peng & Nunes, 2017, Neirotti *et al*, 2014; Nam & Pardo, 2011, Bélissent, 2010). Therefore, there is an increasingly recognition of the need for researchers to explore the diverse socio-technical issues that may affect

Smart City development. Such issues include citizen perceptions and concerns about data privacy and security (Belanche-Gracia *et al*, 2015), the role of big data, data management and open data (Hashem *et al*, 2016; Pereira *et al*, 2017), and factors influencing engagement with smart applications and services (Yeh, 2017; Dehghani *et al*, 2018; Sepasgozar *et al*, 2019). However, most of these studies focused on Smart Cities as a whole, rather than focusing on a particular domain or application. One under-researched area, in which there have already been significant developments, is Smart Parking.

2.2 Smart Parking

By making transport more efficient Smart Parking can help to reduce congestion and noise; thereby making cities cleaner, quieter, cheaper, and more effective. As a result, systems which use advanced technologies to help motorists locate, reserve, and pay for parking have been implemented in many European, American, and Japanese cities (Rodier & Shaheen, 2010).

Smart Parking schemes match the requirements of drivers to the availability and location of parking spaces in real-time. They therefore need to use technologies capable of showing the position of parking places relative to the driver's position and recognise the current status of a space: available or unavailable. Parking Guidance and Information systems (PGI systems) have been popular since the 1980s (e.g. Polak, Hilton, Axhausen & Young, 1990; Axhausen *et al*, 1994), and typically consist of the following:

- Roadside Variable Message Signs (VMS) capable of displaying a limited set of pre-defined (and variable) messages;
- A counting mechanism to record the number of cars entering and leaving car parks;
- A control centre that can process data on car park occupancy and control the display of information on the VMS;
- A telecommunications network that facilitates exchanges of information between car park, control centre and VMS (Polak *et al*, 1990).

Such schemes, however, have inherent disadvantages. Information on VMSs can only be seen by drivers already in traffic who are approaching their destinations where the VMSs are physically installed (Teodorović & Lučić, 2006). Therefore, instead of searching speculatively for parking spaces which may be available, in many occasions, drivers who receive the same information compete for spaces which were available at the time of the last update (Geng & Cassandras, 2012). More importantly, PGI systems are only of use for finding off-street parking (e.g. car garages with relatively simple parking conditions). PGIs however are not suitable for on-street parking spaces, which are associated with more complicated road environment and higher crash risks (Edquist *et al*, 2012). This is a significant issue since research suggests that in many places, on-street parking spots are in far higher demand than other forms of parking. For example, Marshall, Garrick and Hansen (2008) found that demand for on-street parking spaces in six U.S. towns had an average non-peak occupancy of 81.6% and a peak occupancy of 94.5%, making them considerably more popular than either off-street parking or multi-storey car parks.

The need to make on-street parking smarter is being addressed by a new generation of Smart Parking solutions, which have emerged more recently in the 21st Century. Wireless sensors beneath each parking space on a street relay information about the status of that parking space to drivers who use a smart phone app to navigate to available parking (Pierce & Shoup, 2013; Mingardo, van Wee & Rye, 2015). Such apps can draw on technology built into a smart phone, such as GPS and electronic payment services, to navigate drivers to an available space and for payment of parking fees.

Until recently, Smart Parking systems sought to increase efficiency by allowing drivers to make choices based on up-to-date information. Increasingly, however, systems seek to optimise allocation of parking spaces by delegating the choice of parking place to some form of algorithmic approach, which assigns spaces according to pre-established criteria. For example, Geng & Cassandras (2012)

describe a system which takes into consideration cost of parking and the walking distance between the parking place and the driver's final destination.

However, like all information systems, Smart Parking schemes need to be considered within the context of the social and economic environment into which the technology is applied (Rodier & Shaheen, 2010; Peng *et al.*, 2017). Such factors can have a considerable influence on the success of Smart Parking systems and on the nature of its impact. Pricing strategies, and policies that affect the availability of parking throughout the day, have been used to change driver behaviour in ways that discourage drivers from parking at busy times and encourage commuters to make greater use of public transport (Teodorović and Lučić, 2006, Giuffrè and Siniscalchi, 2012). Such initiatives can contribute to a reduction in congestion, and the tools associated with Smart Parking can help to implement them.

In general, there is a very rich amount of research focusing on technology adoption and usage, such as e-commerce (Huy *et al.*, 2012), social media (Rouibah and Hamdym 2009; Oghuma *et al.*, 2016), online banking (Khan *et al.*, 2017), e-services (Xu *et al.*, 2013), mobile government (Talukder *et al.*, 2020), and even smart technologies (Shin *et al.*, 2018, Zhang *et al.*, 2021). In the context of Smart Parking, some attempts have been made to identify and analyse user behaviors associated with the usage of such technology, for example the work by Rodier & Shaheen (2010) who surveyed users of a Smart Parking project designed to promote use of the Bay Area Rapid Transport system in California and gained insights into user patterns (e.g. usage frequency and travel effects) of the project. However, on the whole it is rare to find studies looked into factors affecting the usage of Smart Parking schemes. In this paper we further research on the effect of sociological factors by considering user engagement with a Smart Parking scheme in London. Data collected from the general public regarding their use of on-street parking facilities is analysed to determine the most influential factors.

3. ESTABLISHING THE THEORETICAL MODEL

3.1. Theoretical models and user acceptance

In recent years there has been considerable research into factors which affect the acceptance of new information technologies. Several models have been introduced which consider different aspects of user acceptance, such as Technology Acceptance Model or TAM (Davis, 1985), the Unified Theory of Acceptance and Use of Technology or UTAUT (Venkatesh *et al.*, 2003), Theory of Planned Behavior or TPB (Ajzen, 1991), and Innovation Diffusion Theory or IDT (Roger, 1995). In general, however, the models seek to address two key questions:

1. Do peoples' perceptions of a new technology influence its use?
2. What factors influence the use of a new technology?

The proposed model developed in this article (Figure 1) addresses the same questions, but with a focus on specific aspects relevant to Smart Parking.

3.2. Do Peoples' Perceptions of a New Technology Influence its Use?

Perceived Ease of Use (PEoU) and Perceived Usefulness (PU) were two of the factors in the Technology Acceptance Model (TAM) and are defined as (respectively) "*the degree to which an individual believes that using a particular system would be free of physical and mental effort*" and "*the degree to which an individual believes that using a particular system would enhance his or her job performance*" (Davis, 1985). Both factors have been widely incorporated in models exploring the acceptance of technologies used in Smart Cities and Smart Parking schemes (Kianpisheh *et al.*, 2011; Aylin *et al.*, 2017; Sepasgozar *et al.*, 2019). The possible impact of PEoU and PU on usage of Smart Parking is explored in H1 and H2, respectively.

H1: Perceived Ease of Use affects the use of the parking scheme (H5)

H2: Perceived Usefulness affects the use of London's Smart Parking scheme (H7)

3.3. What Other Factors Influence the Use of a New Technology?

One factor that has long been recognised as affecting the adoption of new technologies in general, arises from the experiences and opinions of people important to the potential user (Davis, 1985). Social influence (SI) is incorporated into a number of widely used models of technology acceptance, including TAM and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh *et al*, 2003). In the proposed model the possible impact on usage of Smart Parking was explored in H3. The possibility that SI affects PU is explored in H4.

H3: Social Influence affects the use of London's Smart Parking scheme (H10)

H4: Perceived Usefulness is affected by Social Influence (H13)

Of specific relevance to Smart Parking is the potential contribution that associated technologies can make to Cost Saving (CS). Studies have shown that parking costs affect driver behaviour (Teodorović & Lučić, 2006). However, better-organised and more flexible parking has the potential to reduce costs indirectly through reduced fuel consumption (Shoup, 2005; Rodier & Shaheen, 2010; Fabusuyi, Hampshire & Hill, 2013; Lan & Shih, 2014; Peng, Nunes & Zheng, 2017). The possibility that CS plays a part in motivating the use of Smart Parking and PU is considered in H5 and H6, respectively.

H5: Potential Cost Savings affect the use of London's Smart Parking scheme (H8)

H6: Perceived Usefulness is affected by potential Cost Savings (H11)

Privacy and security have long been issues of concern affecting the use of new technologies. Where financial transactions, such as payment for parking, are involved (Rodier & Shaheen, 2010) reasons for such concerns are obvious; but additional risks also exist. Security of information is a concern because of some of the new protocols being developed for online services in mobile environments, such as cars seeking parking spaces. Vehicular Ad hoc NETWORKS (VANETs) provide a key role in Intelligent Transport Networks and technical issues or malicious activity, such as Denial of Service attacks, could impair the decision-making of motorists and adversely affect traffic flow (Di Maio *et al*, 2016). Information security also relates to issues of privacy: data could be used to infer movements and routines, creating possible threats to driver safety and privacy. As a result of such concerns, perceived privacy and perceived security have been widely incorporated into models exploring the acceptance of Smart Cities and Smart Parking schemes. For example, Sepasgozar *et al* (2018) included all three factors in their Urban Services Technology Acceptance Model (USTAM) and both factors are included in our new proposed model. H7 and H8 are explored to determine whether perceived privacy and perceived security have a direct impact on the use of Smart Parking. We also consider whether peoples' perceptions of security may affect their perceptions of privacy (H9).

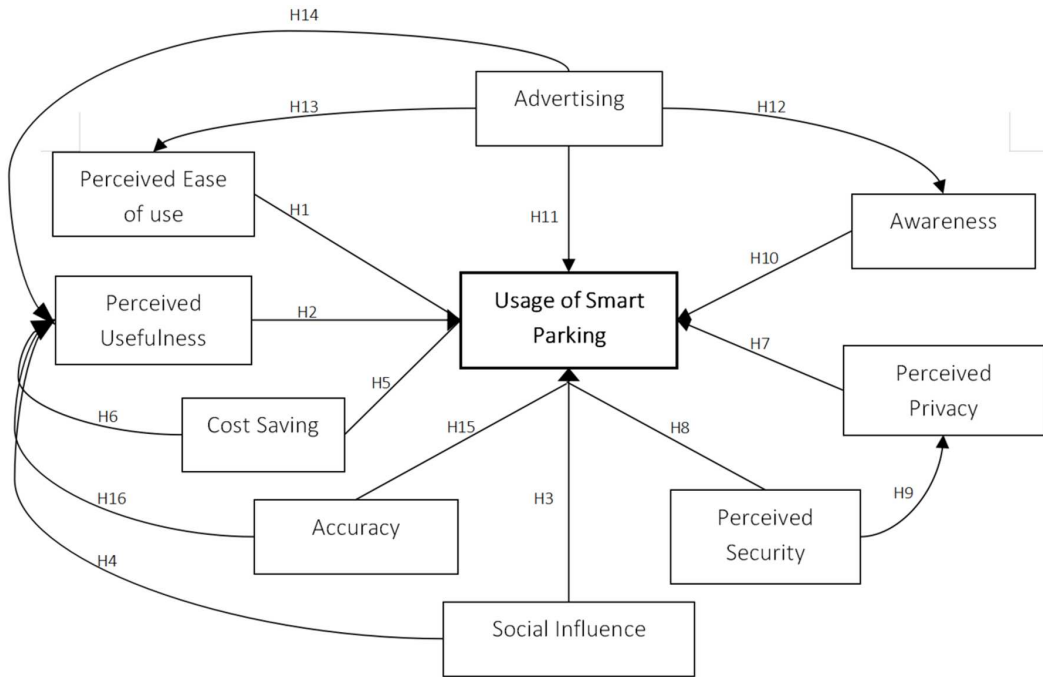
H7: Perceived Privacy affects the use of London's Smart Parking scheme (H14)

H8: Perceived Security affects the use of London's Smart Parking scheme (H15)

H9: Perceived Security affects Perceived Privacy (H16)

For a Smart Parking scheme to be useful information must not only be secure; it must also be accurate. New technologies are being used increasingly to ensure that information is up-to-date (e.g., Maria *et al*, 2016). However, unless the existence and merits of such a scheme are effectively

Figure 1. A summary of the variables and hypotheses investigated in this study



publicised, the scheme is likely to be under-used (Peng, Nunes & Zheng, 2017). The possible impact of Accuracy, Advertising and Awareness on usage of Smart Parking is assessed in H10-H16.

H10: Use of London’s Smart Parking scheme is affected by awareness of the scheme (H1)

H11: Use of the scheme is affected by the advertising of it (H2)

H12: Awareness of the scheme is affected by the advertising of it (H3)

H13: Perceived Ease of Use is affected by the advertising of the scheme (H4)

H14: Perceived Usefulness is affected by advertising of the scheme (H6)

H15: Accuracy of the ParkRight App affects the use of London’s Smart Parking scheme (H9)

H16: Perceived Usefulness is affected by the Accuracy of the ParkRight App (H12)

3.4. The Proposed Model

The factors discussed above are incorporated into the proposed theoretical model, which comprises ten factors connected by sixteen hypotheses.

4. RESEARCH METHODOLOGY

4.1. ParkRight: London’s On-Street Smart Parking Service

According to the UK’s Department for Transport (2018) in 2017 there were nearly 2.8 million cars and light goods vehicles registered in London, making it one of the most congested cities in the UK. A particularly congested region is the City of Westminster: in 2017, it had an average of 24 cars and light goods vehicles registered per hectare (Greater London Authority, n.d.). Westminster is also subject to considerable traffic from other parts of London: it is the location of the UK’s parliament, home to the headquarters of many UK Government departments, and contains numerous tourist

attractions and popular shopping areas. To address some of the problems arising from the resulting congestion, Westminster City Council have invested almost £890,000 (\$1.4million) to implement a Smart Parking system (Curtis, 2014). In a pilot project, 189 sensors were installed in on-street parking spaces in five streets. The pilot was successful enough to justify the expansion of the system to 3,000 sensors by 2014 (Collins, 2014).

The scheme uses three technologies to collect, analyse, and disseminate real-time information regarding the availability of parking spaces. Wireless sensors detect whether or not parking bays are occupied. This data is relayed to a parking management tool, which then updates a mobile app ('ParkRight') capable of directing drivers to available parking spaces (Telegraph, 2014).

This is the first and largest project of its kind in the UK and had been in use for a number of years by the time of this research. As has been noted, the City of Westminster is home to numerous tourist attractions, leading to a lot of leisure traffic. More importantly however, Westminster also houses the UK parliament and many government offices, which generate a considerable amount of commuter traffic. Commuters have substantially less flexibility than tourists in the choice of when and where to park, which increases pressure on the limited parking spaces. In such an environment, people are likely to be motivated to use a resource (such as a Smart Parking scheme) that would make parking easier. This makes the City of Westminster a highly suitable context to carry out an empirical study into sociological factors impacting user engagement of Smart Parking technologies.

4.2. Questionnaire Survey

Questionnaire-based surveys are an efficient and economical way to collect large samples of data from across a wide area over a short period of time (Peng & Annansingh 2013; Bryman 2004: 133–134). For this study, a questionnaire was developed to assess the influence of the factors shown in Figure 1 on the smart parking scheme in London. The questionnaire was designed in two parts: Part 1 gathered demographic information, such as age, gender and education; Part 2 used 5-point Likert-scale items ranging from 'strongly disagree' to 'strongly agree' to investigate the factors listed in Figure 1. The actual constructs/factors and items designed in the survey, together with definitions and sources are presented in Table 2. Each construct has 3 associated items, one of which (given in *italics* in Table 1) was purposely phrased to reflect the opposite opinion of the other two in order to make respondents think more carefully when filling in the survey and so increase the quality of their responses. Moreover, the questionnaire was subject to a pilot test involving 15 MSc and PhD students in the researchers' own institution. Based on the responses to this study, the questionnaire was improved by rewording five of the items and removing typographical errors.

4.3. Sampling and Data Collection

The research team collected data from drivers who regularly visited the West End of London, where the Smart Parking service operates. This was based on the assumption that these drivers were more likely to be users of the Smart Parking service than visitors to London, or London residents who worked in other parts of the city.

In order to better explain the study to target respondents as well as to enhance data quality and response rate, the research team made an effort to carry out the questionnaire in person (rather than in conventional online form). As such, data was collected by researchers who visited different on-street parking areas in the West End of London. They approached drivers who had parked the car in the area, explained the project, and invited the drivers to complete the questionnaire. If a driver did not have time, or was unwilling to complete the questionnaire on the street, the researchers referred them to an electronic version available on Google Forms. The sampling method is therefore a non-probability sample. A total of 1,044 drivers were approached in this way and 212 completed the survey in full, representing a response rate of 20.3%. Amongst the respondents, 179 drivers filled in the questionnaire immediately; 33 completed the online survey later. The demographic profile of respondents is given in Table 2 and the results and findings from this study are presented below.

Table 1. Questionnaire constructs and sources

Construct	Definition	Items	Sources
Awareness (AW)	The extent to which citizens are aware of Smart Parking and its benefits.	AW1: I often hear about the smart car parking service in West End;	Peng, Nunes & Zheng, (2017)
		AW2: I know the benefits that I can get from the ParkRight app;	
		AW3: I am not sure why the smart parking service is needed.	
Accuracy (AC)	The extent to which information provided by Smart Parking services is accurate and reliable.	AC1: Information provided by the smart parking service is accurate;	Maria <i>et al</i> (2016)
		AC2: I feel information shown in the ParkRight app has high level of accuracy;	
		AC3: I receive misleading and inaccurate parking information from the smart parking app.	
Advertising (AD)	The extent to which the provider has promoted the Smart Parking service to potential users.	AD2: The advertisement about smart car parking can always be seen around the city;	Peng, Nunes & Zheng, (2017)
		AD3: I feel the provider is not advertising the smart car parking service enough.	
Perceived Ease of Use (PEOU)	The extent to which the service is perceived to be easy to use.	PEOU1: I think the London smart parking app is easy to use;	Davis <i>et al</i> (1989)
		PEOU2: I can use the smart parking service without requiring any additional support.	
Social Influence (SI)	The extent to which citizens' opinions of Smart Parking are affected by the people surrounding them	SI1: People that I know feel positive about the smart parking service;	Venkatesh <i>et al</i> (2000)
		SI2: When I talk to people about smart parking, they usually give good comments about it;	
		SI3: People around me don't like using the smart parking service.	
Perceived Usefulness (PU)	The extent to which the Smart Parking service is considered to be useful	PU2: I think the smart parking service is useful and effective;	Davis <i>et al</i> (1989)
		PU3: This smart parking service is useless and not doing its job.	
Perceived Security (PS)	The extent to which citizens perceive that their data in the Smart Parking app is securely protected	PS1: The smart parking app has high level of data security;	Lin & Lu (2015)
		PS2: I think that data in the smart parking service is securely protected;	
		PS3: I don't think it is secure to use the smart parking app to search and pay for parking spaces.	
Perceived Privacy (PP)	The extent to which citizens perceive that their personal data in the Smart Parking app is treated as confidential	PP1: I think my data stored in the smart parking app will be treated as confidential and will not be accessed by unauthorised parties;	Sepasgozar <i>et al</i> (2019)
		PP2: I trust the smart parking system's data privacy policy;	
		PP3: Using the smart parking app has a high level of data privacy risk.	
Cost Saving (CS)	The extent to which the service can reduce citizens' parking costs	CS1: The smart parking service can lead to petrol and cost saving;	Teodorović & Lučić (2006)
		CS2: The service can help me to reduce parking searching time and petrol usage;	
		CS3: I don't think it saves my petrol usage with the smart parking service.	
Usage (US)	Frequency of use of the Smart Parking service.	US1: I often use London's smart parking service; US2: I use the ParkRight app on a regular basis; US3: I don't usually use this app when searching for parking space	Davis <i>et al</i> (1989)

Table 2. Demographics of the collected data (N = 212)

Measure	Response	Frequency	%
Gender	Male	120	56.6
	Female	92	43.4
Age	18-24	54	25.5
	25-34	52	24.5
	35-44	60	28.3
	45-59	34	16.0
	60 or above	12	5.7
Education level	Less than high school	12	5.7
	High school diploma	58	27.3
	Bachelor degree	90	42.5
	Master degree	41	19.3
	PhD degree	11	5.2
Monthly income	£1,499 or less	62	29.2
	£1,500-£2,499	50	23.6
	£2,500-£3,499	50	23.6
	£3,500-£4,499	36	17.0
	£4,500 or more	14	6.6
Connection with London	Live or work there	187	88
	Just visiting	25	12

5. DATA ANALYSIS AND RESULTS

The data was analysed using SPSS plus AMOS 20. Results and findings are presented and discussed below.

5.1. Confirmatory Factor Analysis and Reliability Tests

To confirm that the collected data has sufficient reliability and validity, a Confirmatory Factor Analysis (CFA) on the measurement model was performed. The results of the CFA (Table 4) resulted in four items being removed from the analysis: one item respectively from PEOU, AD, PU and US. These items lack reliability (with a factor loading score below 0.5) and by removing them the researchers were able to suggest a better measurement scale (Lewis-Beck, 1994; Mojtahed *et al*, 2014). The reliability of the data was assessed using Cronbach's alpha. Opinions differ about what value of Cronbach's alpha is acceptable. Researchers, such as Davis (1964) and Nunnally (1978) have suggested that acceptable values are between 0.5 and 0.6 for new scales. A stricter acceptance value of 0.7 was proposed by Kaplan & Saccuzzo (2008) and Nunnally & Bernstein (1967).

As shown in Table 3, the results of Cronbach's alpha test for all variables exceeded the lower acceptance values, and one (Advertising) narrowly fell short of the higher acceptance value. Therefore, the collected data was considered to be internally reliable. Furthermore, convergent validity was measured by Composite Reliability (CR) and Average Variance Extracted (AVE). The CR values shown in Table 3 were all above 0.82 (higher than the acceptable value of 0.7), and AVEs were all higher than the suggested acceptable value of 0.5 (Lin & Lu, 2015). These results indicate good convergent validity of the measurement scales. To determine discriminant validity, the shared variances between

Table 3. Descriptive statistics and convergent validity

Constructs	Items	Factor loadings	Mean	SD	Cronbach's alpha	CR	AVE
Awareness (AW)	AW1	0.783	2.48	1.21	0.864	0.88	0.62
	AW2	0.852					
	AW3	0.801					
Accuracy (AC)	AC1	0.893	3.13	1.33	0.853	0.85	0.71
	AC2	0.862					
	AC3	0.870					
Advertising (AD)	AD2	0.880	3.16	1.26	0.686	0.91	0.65
	AD3	0.848					
Perceived Ease of Use (PEOU)	PEOU1	0.847	3.43	1.35	0.769	0.86	0.73
	PEOU2	0.889					
Social Influence (SI)	SI1	0.801	3.71	1.07	0.788	0.89	0.78
	SI2	0.891					
	SI3	0.809					
Perceived Usefulness (PU)	PU2	0.836	4.12	1.28	0.744	0.90	0.84
	PU3	0.911					
Perceived Security (PS)	PS1	0.838	3.76	1.35	0.823	0.87	0.61
	PS2	0.884					
	PS3	0.760					
Perceived Privacy (PP)	PP1	0.854	3.35	1.21	0.854	0.82	0.67
	PP2	0.864					
	PP3	0.836					
Cost Saving (CS)	CS1	0.844	3.41	1.04	0.811	0.85	0.76
	CS2	0.782					
	CS3	0.897					
Usage (US)	US1	0.896	3.74	1.18	0.895	0.93	0.82
	US2	0.859					

constructs were compared with the AVEs for individual constructs. Table 4 shows that the AVEs were all higher than the shared variances. The measurement scales thus have good discriminant validity (Fornell & Larcker, 1981).

To ensure that the factors in our model were not correlated (i.e., non-significant multicollinearity), the Variance-Inflation Factor (VIF) and tolerance were calculated. The results showed that the tolerance indicators for all the factors in the model are greater than 0.1, with corresponding VIF values being below 10. These values conform to the common cut-off threshold (Hair *et al.*, 1998), indicating that multicollinearity is not a concern.

Prior to testing the hypotheses, the researchers also assessed the overall Goodness-of-fit of the measurement model using six common measures: χ^2/df , Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Normed Fit Index (NFI), Comparative Fit Index (CFI), and Root Mean Square Error of Approximation (RMSEA). Results for goodness-of-fit were as follows: $\chi^2/\text{df}=2.16$,

Table 4. Discriminant validity

Construct	AW	AC	AD	PEOU	SI	PU	PS	PP	CS	US
AW	<i>0.71</i>									
AC	0.21	<i>0.76</i>								
AD	0.26	-0.11	<i>0.78</i>							
PEOU	0.14	0.26	0.21	<i>0.89</i>						
SI	0.35	0.15	0.32	-0.11	<i>0.85</i>					
PU	-0.21	0.23	0.18	0.23	0.31	<i>0.85</i>				
PS	-0.11	-0.06	0.35	0.09	-0.13	0.32	<i>0.74</i>			
PP	0.23	0.23	0.12	0.36	0.41	0.11	0.16	<i>0.86</i>		
CS	0.41	0.13	0.03	0.13	0.22	0.28	-0.08	0.37	<i>0.74</i>	
US	0.22	-0.06	0.36	0.27	0.18	0.43	0.39	0.29	0.36	<i>0.73</i>

Note: Off-diagonals are shared variances; diagonals (italic) are square roots of AVEs; for discriminant validity, diagonals should be higher than off-diagonals.

GFI=0.919, AGFI=0.84, NFI=0.80, CFI=0.905, and RMSEA=0.053 (see Table 5). All indices exceeded the recommended values (e.g., Lin & Lu, 2015; Mojtahed *et al*, 2014; Scott, 1994; Hair *et al*, 1998; Bagozzi & Yi, 1988), indicating that the measurement model achieved an adequate fit.

Overall, the range of test results confirmed that the questionnaire was adequate for the purpose of collecting reliable and valid data and could be used to test the hypotheses listed above.

5.2. Testing the Structural Model

5.2.1 Hypothesis Testing

The structural model and hypotheses associated with the defined factors were tested using AMOS 22.0. As shown in Table 5, the structural model also has an adequate model fit ($\chi^2/df=2.13$, GFI=0.912, AGFI=0.832, NFI=0.822, CFI=0.914, RMSEA=0.051). Results of the hypotheses analysis are shown in Table 6 and indicate that usage of London's Smart Parking service is significantly affected by Awareness ($\beta=0.765$, $p<0.001$), Perceived Ease of Use ($\beta=0.328$, $p<0.001$), Perceived Usefulness

Table 5. Goodness-of-fit measures for the structural model

Statistics	Recommended values	Measurement model	Structural model
χ^2 (df)	-	267.801	264.712
$\chi^2/(df)$	< 3	2.16	2.13
P	> 0.05	0.06	0.07
Degree of freedom	-	161	159
Goodness-of-fit index (GFI)	> 0.90	0.919	0.912
Adjusted goodness-of-fit index (AGFI)	> 0.80	0.840	0.832
Root mean square error of approximation (RMSEA)	< 0.06	0.053	0.051
Normed fit index (NFI)	> 0.80	0.800	0.822
Comparative fit index (CFI)	> 0.90	0.905	0.914

Table 6. Hypothesis testing in the structural model

Hypothesis	Relationship	Standardized coefficient (β)	Results
H1	PEOU→US	0.328**	Supported
H2	PU→US	0.442*	Supported
H3	SI→US	0.433 ^{ns}	Not supported
H4	SI→PU	0.610**	Supported
H5	CS→US	0.351**	Supported
H6	CS→PU	0.460**	Supported
H7	PP→US	0.325*	Supported
H8	PS→US	0.496**	Supported
H9	PS→PP	0.765**	Supported
H10	AW→US	0.765**	Supported
H11	AD→US	0.341 ^{ns}	Not supported
H12	AD→AW	0.556**	Supported
H13	AD→PEOU	0.269 ^{ns}	Not supported
H14	AD→PU	0.426 ^{ns}	Not supported
H15	AC→US	0.385 ^{ns}	Not supported
H16	AC→PU	0.374**	Supported
Notes: *** $p<0.001$; ** $p<0.01$; * $p<0.05$			

($\beta=0.442$, $p<0.05$), Cost Saving ($\beta=0.351$, $p<0.001$), Perceived Security ($\beta=0.496$, $p<0.001$), and Perceived Privacy ($\beta=0.325$, $p<0.05$). Therefore, Hypotheses 1, 2, 5, 7, 8 and 10 were supported. In contrast, no significant relationship could be found between Usage and Advertising, Accuracy of information, and Social Influence; therefore, Hypotheses 3, 11 and 15 were rejected. Advertising was found to have a direct impact on citizens' awareness ($\beta=0.556$, $p<0.001$), but no significant influence on Perceived Ease of Use or Perceived Usefulness. Therefore, Hypothesis 12 was validated, but Hypotheses 13 and 14 were rejected. Cost Saving ($\beta=0.460$, $p<0.001$), Accuracy ($\beta=0.374$, $p<0.001$) and Social Influence ($\beta=0.610$, $p<0.001$) were all significantly associated with Perceived Usefulness; and Perceived Security was found to impact on Perceived privacy ($\beta=0.765$, $p<0.001$). These results validated Hypotheses 4, 6, 9 and 16 respectively. Figure 2 presents a summary of these results, allowing direct comparison with the original research model (Figure 1).

5.2.2 Demographic Factors

Five demographic factors were included in the survey (Table 2). These were tested against the ten factors in the model (Figure 2) to identify significant correlations (using Spearman Correlation Coefficient). Since this resulted in 50 tests, the threshold for significance was set at $p=0.01$ instead of $p=0.05$ (i.e., each test had a 1 in 100 chance of falsely showing as significant, as opposed to the usual level of 1 in 20).

Results suggest that, overall demographic factors had little influence. Age was the most important demographic factor (Table 7), with older respondents proving more likely to be aware of the scheme, and less susceptible to Social Influence. Income was also significantly correlated to awareness, with more highly paid respondents tending to show greater awareness. Commuters and residents were significantly less likely to be influenced by accessibility than visitors to London, possibly because

Figure 2. Empirical model based on SEM analysis

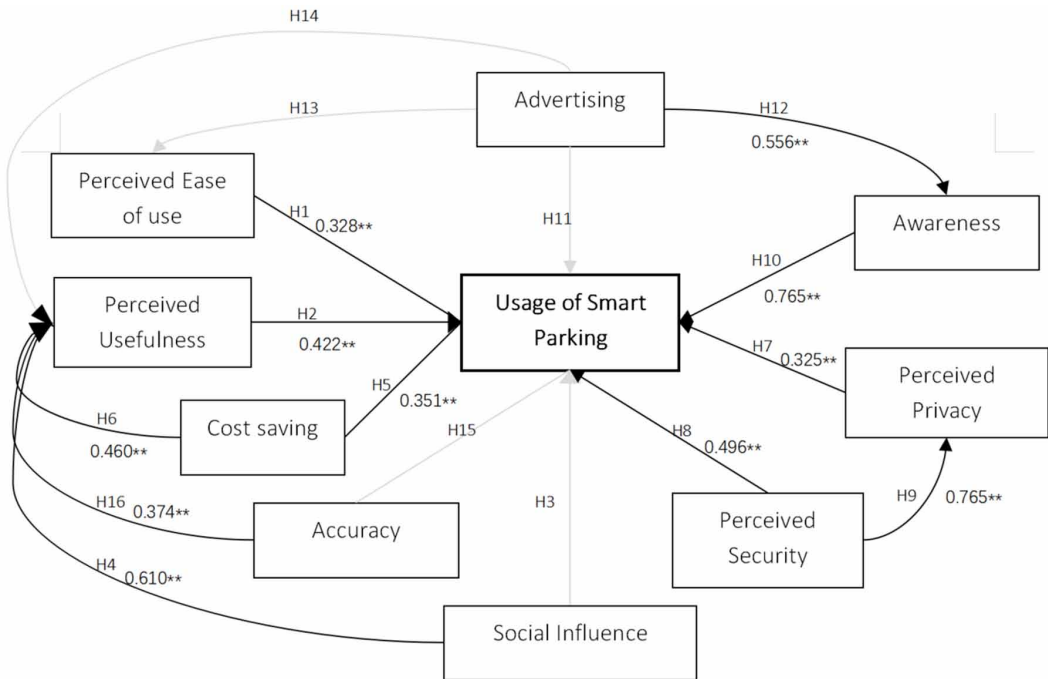


Table 7. Significant demographic Spearman correlations

	Age	Income	Working/living or travelling?
Awareness	0.298**	0.297**	
Accessibility			-0.232**
Social influence	-0.210**		

they had a more comprehensive knowledge of local parking schemes allowing them to adopt a wider range of criteria when choosing where to leave their vehicles.

6. DISCUSSION

6.1. Addressing the Research Questions

The questions posed in section 3 were explored using the SEM presented in Figure 1, which is built around 16 hypotheses. Tests of the hypotheses confirm that peoples' perceptions (PEoU and PU) did influence the use of the Westminster Smart Parking scheme. Two factors (Cost Saving and Social Influence) were initially thought to motivate people to use the scheme. Cost Saving had a direct influence on usage; however, Social Influence did not. This aligns with findings from existing research. For example, Venkatesh *et al.* (2003) found that in a voluntary setting, the effect of Social Influence was indirect and influenced peoples' perceptions about the technology. This was the case in this study, where H4 (*Perceived Usefulness is affected by Social Influence*) proved to be significant.

Perceived Security and Perceived Privacy influenced the use of the scheme, but the most influential factor in the adoption of London's Smart Parking scheme proved to be Awareness. As reported elsewhere (Peng *et al*, 2017), despite substantial efforts to advertise the Smart Parking scheme, nearly three quarters (156 out of 212) of the respondents had seldom heard of it. Advertising may have had some impact on overall awareness (Figure 2, H12), but it seems to have had little direct influence on usage of the parking scheme, or on perceptions of the scheme's usefulness and usability (Figure 2, H11, H13, H14) reinforcing the point made by Peng *et al* (2017) that advertising needs to be not only widespread, but appropriate. The positive correlation between age and Awareness (Table 7) suggests that the advertisers may have focused on traditional channels, and neglected to make full use of the potential of newer means of raising awareness, such as social media, to attract the attention of the younger generation.

In summary, the model presented in Figure 2, like many others relating to the use of Smart Parking, found Perceived Ease of Use, Perceived Usefulness, Perceived Security, Perceived Privacy, and Cost Saving to be significantly associated with Usage of Smart Parking. However, lack of awareness means that interpretation of the model must, of necessity, be tentative. It is highly likely that the impact of some factors is underestimated since responses to the questionnaire were dominated by the views of people less familiar with the scheme.

6.2. Theoretical Implications

The study has a number of important theoretical implications. This is one of the few studies to have investigated technology usage and user behaviour in the context of Smart Cities in general, and Smart Parking in particular. It reinforces findings relating to earlier studies surrounding the adoption of new smart technologies by confirming the importance of Perceived Ease of Use (e.g., Davis *et al*, 1989), Perceived Usefulness (e.g., Davis *et al*, 1989), Perceived Security (e.g., Lin & Lu, 2015), Perceived Privacy (e.g., Sepasgozar *et al*, 2019) and Awareness (e.g., Peng *et al*, 2017). In addition, it provides evidence to support the view that Cost Saving, Accuracy, and Social Influence can shape people's perceptions of the usefulness of smart parking schemes, and so either directly or indirectly affect citizens' willingness to use such technology. Overall, the results of this study provide a theoretical foundation for future research into behaviour associated with smart technologies in a city context.

6.3. Practical Implications

The findings of this study provide new insights into key factors affecting the usage of Smart Parking schemes, not just in London but more widely. The evidence gathered suggests that potential users of smart parking could be deterred by the energy and effort required to learn how to use the scheme, as well as by concerns over data privacy and security risks. Designers of Smart Parking apps should, therefore, ensure that the interface is simple and clear and requires minimal effort. However, to ensure data privacy and to reduce risks to security, city governors cannot just rely on technical solutions (Dutta *et al*, 2013). Rigorous data protection regulations need to be established and clearly enforced, to make sure that citizen data captured through smart apps cannot be misused or accessed by unauthorized parties (Dutta *et al*, 2013). The study also found that perceptions of the usefulness of Smart Parking schemes is dependent on potential cost savings, the quality of information provided, and the views of friends and family members. These factors should thus be fully considered in any marketing and promotion strategies aimed at attracting the interest of citizens, raising their awareness and increasing their use of the scheme. In sum, city governors, app developers, and service providers in London and elsewhere should consider the findings presented to improve the quality and usage of smart parking schemes and to realise their potential benefits.

6.4. Limitations and Future Studies

While this study contributes to both theory and practice we also recognize that it has limitations, especially with respect to the survey sample. Since the study only involved residents of, and visitors

to, London, who volunteered to participate the generalizability of its findings is reduced. In addition, this research focuses specifically on Smart Parking, which is just one of a range of smart schemes and services deployed in modern cities. However, the factors identified and hypotheses confirmed may be relevant to other smart city initiatives (e.g., cost saving and information accuracy are arguably also relevant to smart bus schemes), though this needs further investigation and testing.

Given these limitations and the current scarcity of studies investigating usage and behaviour in the smart city context, further research in this area is strongly recommended. Future research can draw on the research model and findings of this study, and seek to test the validity of the model by assessing its relevance to other cities and other smart city schemes.

7. CONCLUSION

London is a major tourist destination, so demand for parking is high across the city. However, because Westminster is the location of many prominent employers (primarily, the UK government) much of this demand comes from commuters rather than leisure travellers. This is significant, because commuters have far less flexibility than tourists in their choice of where and when to park.

Westminster City Council invested approximately £890,000 in the Smart Parking scheme, demonstrating a clear commitment to the idea of using IoT technologies to improve transport in the Borough.

These two observations make the findings of this study particularly surprising. Because commuters working in Westminster are restricted in their choice of parking, they would have been interested in developments designed to make parking easier and more flexible. Since Westminster City Council have invested a significant proportion of its income on a scheme designed to improve parking, it would have been keen for the Smart Parking scheme to be well-used. However, despite the fact that the scheme's provider had a clear motivation for publicising the scheme, and the target users had a clear motivation for finding out about it, awareness (or, more accurately, lack of awareness) proved to be the most influential factor in the adoption of London's Smart Parking scheme.

This disconnect between providers of a technological solution and potential beneficiaries of the solution, is another example of the way in which social factors can impact on the implementation of technology; and it reinforces the need for researchers to explore the full range of socio-technical issues that may affect smart city development.

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