Travel Behaviour and Society 21 (2020) 257–264

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

The role of numeracy and financial literacy skills in the relationship between information and communication technology use and travel behaviour

Jinhyun Hong[a,*], Piyushimita (Vonu) Thakuriah[b], Phil Mason[c], Catherine Lido[c]

[a] Department of Urban Studies, The University of Glasgow, Glasgow, United Kingdom
[b] Edward J Bloustein School of Planning and Public Policy, Rutgers University, USA
[c] School of Education, The University of Glasgow, Glasgow, United Kingdom

ARTICLE INFO

Keywords:
ICT
Numeracy
Travel behaviour
Financial literacy
Digital divide

ABSTRACT

The present research examines the role of maths-related literacies, or competencies, in influencing the relationship between ICTs and travel behaviour. We adopted a Bayesian approach to jointly model the frequency of different types of internet use, and total travel distance per traveller, with respect to measures of lifewide literacies (other than reading), specifically in the form of numeracy and financial literacy questions. Our findings revealed that participants with higher levels of these literacies used the internet more frequently, and travelled further than those with fewer skills. These literacies were directly associated with total travel distance, as well as indirectly associated through internet use. Our results therefore imply that a strong policy aim to improve maths-related literacies could have implications for mitigating the effects of social exclusion in the digital age.

1. Introduction

The relationship between information and communication technology (ICT) and travel behaviour has been extensively investigated over several decades (Mokhtarian and Tal, 2013; Hong and McArthur, 2017; Mokhtarian et al., 2006; Hong and Thakuriah, 2016). Most empirical studies have focused on the connections between different types of ICT activities, such as online shopping, telecommuting, and internet use and travel behaviour. However, core competencies, known as 'lifewide literacies', which extend beyond simply reading, such as numeracy and financial literacy, may play a significant role in determining the relationship between ICT use and travel behaviour, and have been less thoroughly studied.

Numeracy, reading/writing literacy and financial literacy are important life skills for actively contributing members of contemporary society. People daily face financial problems (e.g., travel costs, mortgage and personal loans), and numeracy is one of the key factors that can facilitate life judgements and decisions regarding such essential life matters (Ghazal et al., 2014). These literacies are also related to ICT use (e.g., frequency and access) and the level of understanding about information that people will acquire (Peter et al., 2007; De Haan, 2004). Moreover, lower levels of these literacies are closely associated with higher levels of unemployment and social exclusion (Bynner and Parsons, 2001), which influences people's travel patterns. As the importance of ICT in our daily life and the integration of ICT with transport have grown rapidly, the role of core competencies in ICT-transport research has also become more important.

To the best of our knowledge, partly due to the limited availability of suitable data, no empirical studies have yet examined the complex relationship between the three factors (i.e., literacies, ICT use and travel behaviour) simultaneously, or that with an emerging concept of financial literacy (as distinct from numeracy). It is especially important to investigate these matters simultaneously for the benefit of transport, urban and educational planners, because these complex relationships may mean that lower levels of ICT use due to the lack of literacies may exacerbate social exclusion.

In this study, we addressed this matter using survey data from the integrated Multimedia City Data (iMCD) project, conducted by the Urban Big Data Centre (UBDC) at the University of Glasgow, UK. We adopted a Bayesian approach to jointly model the frequency of different types of internet use and total travel distance per traveller with respect to measures of maths-related lifewide literacies (operationalised fully below). As we defined in Lido et al. (2019), lifewide literacies are more than simply reading and writing abilities, and involve "a broad definition involving a continuum of learning, from formal to self-led skills development to enable individuals to achieve goals and actualise potential" (p. 281). More specifically, maths-related literacies concern the ability to work with numbers in everyday life in order to achieve one's

* Corresponding author.
E-mail addresses: Jinhyun.Hong@glasgow.ac.uk (J. Hong), p.thakuriah@rutgers.edu (P.V. Thakuriah), Phil.Mason@glasgow.ac.uk (P. Mason), Catherine.Lido@glasgow.ac.uk (C. Lido).

https://doi.org/10.1016/j.tbs.2020.07.007
Received 3 October 2019; Received in revised form 28 July 2020; Accepted 28 July 2020
Available online 07 August 2020

life goals, such as the application of numeracy in the real world to complete daily tasks or work-based tasks, and financial literacy, which encompasses understanding of economic matters such as investment risk and compound interest. Such maths-related literacies—particularly financial literacy—have been linked to positive life outcomes, like future employment success. These literacies may therefore be a core skill associated with future quality of life (Chiswick et al., 2003; Lusardi et al., 2010). It is worth noting that our justification for focusing on maths-related literacies specifically is partly in response to UNESCO's (2004) criticism of the conception of literacy as a competence restricted solely to reading. Additionally, we theoris that such literacies may play an important role in moderating both ICT use and travel-related decision processes (see literature review below).

The rest of this paper is organised as follows. First, we review the literature about social exclusion, literacies, ICT use and travel behaviour in detail. Second, we describe the data and the method used in our analyses. Third, we present our empirical results about the potential roles of maths-related literacies in determining internet use and total travel distance. Finally, we summarise our results in context and present our conclusions.

2. Literature review

The main aim of this paper is to examine the potential links between maths-related literacies, ICT use and travel behaviour that could lead to forms of social exclusion. In this section, we will review three relevant research streams: 1) social exclusion and transport; 2) maths-related literacies, social exclusion and ICT use; and 3) ICT use and travel behaviour.

2.1. Social exclusion and transport

Social exclusion is a multi-faceted and complex concept (Hodgson and Turner, 2003; Lucas, 2013), and so is hard to define. Nevertheless, Lucas (2013) specified eight core dimensions of social exclusion (i.e., personal, geographic, spatial, temporal, economic, social, cultural and political) and, in their empirical study, Burchardt et al. (1999) proposed the following operational concept of social exclusion: "An individual is socially excluded if (a) he or she is geographically resident in a society but (b) for reasons beyond his or her control he or she cannot participate in the normal activities of citizens in that society and (c) he or she would like to so participate" (p. 229).

For example, residents in rural areas who do not have a private car may be less likely to participate in activities (e.g., hospital appointments, education, shopping) provided in a city centre due to the lack of adequate public transport services and to problems with accessibility. Currie and Delbosc (2010) examined the relationship between transport disadvantage, social exclusion and well-being by using structural equation modelling of questionnaire data. Their results showed that transport disadvantage (i.e., transit disadvantage, transport disadvantage, vulnerability/impairment and reliance on others) has a significant positive relationship with aspects and dimensions of social exclusion (i.e., low income, unemployment, political disengagement, lack of participation and lack of social support). This supports the hypothesis that the lack of public transport services or of access to them could limit physical mobility and, thereby, participation in activities, which would potentially exacerbate aspects of social exclusion. Lucas (2012) also argued that the interaction between transport disadvantage and social disadvantage could cause transport poverty, making various activities inaccessible, eventually leading to social exclusion.

2.2. Maths-related literacies, social exclusion and ICT use

UNESCO (2004) defines literacy as "the ability to identify, understand, interpret, create, communicate and compute […] enabling individuals to achieve their goals, to develop their knowledge and potential, and to participate fully in their community and wider society" (p. 13), providing literacy with a 'functional' purpose in society for personal goal-fulfilment, rather than merely the skill of being able to read. Maths-related literacies are therefore one of the most influential factors in determining the impacts of social exclusion. For example, people with poor numeracy skills are more likely to take semi-skilled or unskilled jobs (Parsons and Bynner, 2005). Green and Owen (2006) found that lower-skilled people tend to have fewer job opportunities due to their geographic constraints. In addition, they have shorter commuting distances than the average for the population as a whole. Bynner and Parsons (2001) study showed that people who have lower qualifications and fewer numeracy skills are more likely to be unemployed. According to the UNESCO approach, maths-related literacies comprise much more than simple numeracy, so the ability to use maths to engage with aspects of society, and more complicated literacies, such as financial literacy, might provide people with the competencies to fully participate in the physical and social world around them. From the above literature, we conjecture that citizens with lower levels of maths-related competencies could be socially excluded, and have more limited travel horizons (i.e., short travel distances).

Stanley et al. (2010) showed that people with a high risk of social exclusion travelled less than the socially included. This negative pattern could be reinforced through the more limited ICT use associated with those lacking such maths-related skills. ICT could help improve mobility-limited social exclusion by increasing the level of accessibility. van Wee et al. (2013) looked at the potential impacts of ICT on the four conceptual components of accessibility. Specifically, they argued that ICT could reduce travel resistances (transport component) and influence accessibility by changing the land-use component, temporal constraints and individual components (e.g., needs and abilities). Golob and Regan (2001) suggested that people could participate in various activities without changing their location because virtual accessibility to them could be increased. This would automatically change the established level of accessibility. Kenyon (2010) argued that virtual mobility could mitigate mobility-based social exclusion by providing alternative options to physical mobility. Specifically, people can use the internet to access opportunities, goods and services rather than making physical trips.

However, some empirical studies imply that the lack of maths-related skills is related to less use of ICT. For example, Jensen et al. (2010) found that health literacy and numeracy of lower-income adults were significantly associated with the use of, and access to, internet technology. Specifically, they found that those with lower levels of health literacy and numeracy skills were less likely to have access to the internet. Peter and Valkenburg (2006) showed that cognitive resources, which vary with age and educational level, shaped patterns of internet use in the Netherlands. Specifically, adolescents with higher educational levels used the Internet more frequently to search for information, but less frequently for entertainment, than those with lower educational levels. Since educational experience is closely associated with levels of most forms of literacies, this finding implies that maths-related competencies may indeed shape internet usage patterns. Carpentieri et al. (2009) indicated that numeracy and digital skills (e.g., computer tasks) were strongly correlated, and people with poorer numeracy were less likely to use computers and the internet than those with higher numeracy and digital competencies. Therefore, the potential benefits of increased virtual accessibility through ICT use are less likely to accrue to those with lower levels of maths-related, as well as digital, literacies.

2.3. ICT and travel behaviour

Many studies have investigated the associations between ICT and transport. Some have examined the relationships of different types of ICT use and travel patterns with detailed travel information (Hong and Thakuriah, 2018; Zhu, 2012; Wang and Law, 2007; Hong and McArthur, 2017; de Abreu e Silva and Melo, 2018; Kim, 2017), while others have examined their relationships with expenditure (Bris et al., 2017; Choo et al., 2007). Statistical models developed to examine their potential bi-directional relationships and to account for the impacts of endogeneity have become well established (Cao et al., 2012; Bris et al., 2017; Zhou and Wang, 2014; Zhu et al., 2018). For example, Zhou and Wang (2014) used structural equation modelling to illustrate that online shopping increases the frequency of shopping trips, while shopping trips discourage online shopping.

Empirical results, however, are mixed. Andreev et al. (2010) reviewed diverse ICT-travel studies, focusing on four major direct effects of ICT (i.e., substitution, complementarity, modification and neutrality) on types of personal activities (i.e., mandatory, maintenance and discretionary). Their review showed that substitution effects were dominant for telecommuting, while complementarity impacts were more prevalent for teleshopping and teleleisure. Mokhtarian (2003) provided detailed explanations about the four types of relationships mentioned above, as well as conceptual, theoretical and empirical evidence from different countries. She argued that although the four relationships could occur simultaneously, empirical evidence pointed to complementarity being the strongest association overall.

One of the widely used assumptions in the previous empirical studies is that ICT use influences travel behaviour. However, other relationships are feasible, as briefly mentioned above. For example, Ben-Elia et al. (2018) proposed two further potential relationships. First, the relationship can be bi-directional (e.g., telecommuting could result in longer commuting distances, while workers who live further from their workplaces are more likely to adopt telecommuting). van den Berg et al. (2013) employed a path analysis approach and examined the interrelationships between individual characteristics, built environments, social networks, ICT use and social travel. Their findings showed that ICT use could replace social travel, while social travel may complement ICT use for social interaction, thereby supporting the bi-directional relationship. Second, there could be a confounding (missing) factor that influences both ICT use and travel behaviour, leading to a significant correlation between them. For example, researchers often ignore "intention to work efficiently on the move" in their models but examine the relationship between ICT-equippedness and travel behaviour. In short, a body of empirical studies illustrates the complex relationship between ICT use and travel behaviour, showing that different relationships exist, depending on the types of ICT use, personal activities and so on.

In summary, the literature attests to the potential relationships between maths-related literacies, ICT use and travel behaviour, and their significant onward implications for social exclusion. Although the three elements appear to be closely related, most empirical studies have examined only pair-wise relationships (e.g., ICT and travel behaviour; maths literacies and ICT use). Therefore, the present research aims to simultaneously model their complicated relationships by taking a Bayesian approach to the analysis of iMCD survey data. We chose to consider numeracy and financial literacy as measures of the level of maths-related literacies because: 1) numeracy and financial literacy both involve mathematical calculation processes and are closely linked; 2) these skills influence travel decisions such as trip-making, car-ownership, scheduling and time/fare calculations; and 3) both have been shown to be predictors of successful employment and wider economic outcomes.

3. Method

3.1. Measures

The iMCD household survey was conducted in 2015 to collect diverse information from residents of the Glasgow and Clyde Valley Planning area (8 local authorities, including Glasgow City) about matters such as household/person characteristics, ICT use, travel activities (based on a one-day travel diary), and other domains such as education (e.g., literacies) and cultural/civic engagement. The survey is part of a larger data infrastructure consisting of travel and activity diaries, sensors, lifelogging, remote sensing, and internet data (Thakuriah et al., 2020). The survey was administered in face-to-face interviews in the homes of 2,095 people from 1,511 households. Its quality was checked by the survey company against the 2014 Scottish Household Survey (Ipsos MORI, 2015), whose own robustness was validated against the 2011 Census for Scotland.

The iMCD household survey was developed following an exhaustive review of (largely UK) national survey questions covering the domains of interest. Content validity was assessed by a team of eight subject-matter experts from interdisciplinary backgrounds. All measures in the survey were incorporated from validated social science surveys and/or standardised national longitudinal surveys, such as the Adult Education Survey (2015), the National Adult Learners Survey (Department for Business Innovation & Skills, 2012), the Scottish Household Survey (2014), and operationalised in line with the harmonised guidelines of the UK Government's Office of National Statistics.

To assess the level of numeracy in 'everyday life', participants were asked a standardised single-item question employed by national surveys such as the Adult Education Survey: "How confident would you say you are in using maths in everyday life, for instance, figuring out how much change is owed, or how much you have saved on a discounted item?". The response was measured on a 4-point ordinal scale, from "not at all confident" to "very confident". Second, the survey includes three questions about financial literacy, taken from the validated short-form measure by Lusardi and Mitchell (2014), where items involve quiz-type multiple-choice questions that test competencies about key financial concepts such as inflation, interest rates and diversification. This is important because financial literacy has been linked to positive life outcomes, such as security in retirement and future wellbeing (Lusardi et al., 2010). The specific questions are: 1) "Suppose you had £100 in a savings account and the interest rate was 2% per year. After 5 years, how much do you think you would have in the account if you left the money to grow" (More than £102/Exactly £102/Less than £102/I cannot tell, not even approximately); 2) "Imagine that the interest rate on your savings account was 1% per year and inflation was 2% per year. After 1 year, how much would you be able to buy with the money in this account" (More than today/Exactly the same/Less than today/I cannot tell, not even approximately); and 3) "Which is the riskier asset to invest in?" (An individual share in a company/A portfolio of different company shares/The risk is the same in both cases/Don't know). We counted the number of correct answers to derive a financial literacy variable with four categories (i.e., 1: no correct answers; 2: one correct answer; 3: two correct answers; and 4: three correct answers). We then created an aggregate maths-related literacy variable by summing the values of the numeracy and financial literacy variables. Although these two variables measure different competencies, it is justifiable to combine them because: 1) numeracy and financial literacy both require a thorough understanding of numbers, percentages and the calculation process; 2) numeracy is an important determinant of financial literacy (Skagerlund et al., 2018); and 3) therefore, the two variables are highly correlated. The resulting *Maths Literacy* variable could take values from 2 to 8, and was treated as a continuous variable in the analytical models.

The frequency of different types of internet activity was constructed from five questions. The survey asks how often the interviewee does the following things online: 1) reading and sending e-mails; 2) using instant messaging; 3) online shopping; 4) banking and paying bills online; and 5) looking at social networking sites or apps. These are among the most popular online activities of internet users in Scotland (Ofcom, 2017). Answers are measured on a 7-point ordinal scale, from "never" to "several times a day". An *Internet Use* variable was created by summing the values of the answers to the five questions. It was treated as an endogenous variable based on the evidence from previous empirical studies.

The iMCD survey includes several questions about interviewee's formal and informal learning engagements, from which we selected two computer skill-related questions as instrumental variables (IVs) (Hong and Thakuriah, 2018). As mentioned in the literature review, some empirical studies have confirmed endogeneity between internet use and travel behaviour. In this paper, we took an IV approach to overcome this potential methodological challenge. The survey asks how confident the interviewee is in fixing computer-related problems (e.g., connecting to a network) and about skills for doing creative things online (e.g., making online profiles and sharing photos). Four responses were possible, from "not at all confident" to "very confident". We used them as continuous variables in the analytical models. We conducted extra analyses (i.e., Wald-test of irrelevance; Sargan test of validity (Hill et al., 2018)) which enabled us to confirm the validity of our IVs.

Total travel distance was calculated from a one-day travel diary, completed alongside the main iMCD survey, in which the participant reported all the trips s/he had made on the day before the interview. Each trip was classified as one of 18 types of activity, including work, shopping, leisure, etc. It is worth noting that interview dates were allocated as evenly as possible across the week to ensure that the diaries were as representative as possible of travel patterns in the Glasgow and Clyde Valley Planning area. We excluded from the analyses a small number of trips made by aeroplane or on horseback, and all participants who recorded zero travel distance.

Several socio-demographic factors and attitudinal factors were also considered in the models. All continuous variables except *Internet Use* were standardized with respect to their means and standard deviations. Table 1 shows the descriptive statistics for all variables (original form) included in the analytical models, as well as the distribution of responses for the original numeracy and financial literacy variables. The average age of the participants was about 49 years and 45% were males. On average, there were 2.55 members in a household and the average annual personal income was £15,862. 34% of our participants had an undergraduate honours or higher degree, and 75% of them held a valid driving licence. About half were in some form of employment. On average, people had more positive attitudes towards walking and driving than about public transport. Similar proportions were numerate and financially literate. However, 52% of the participants claimed to be very confident in numeracy even though only 40% correctly answered all the financial literacy questions. The average total travel distance per traveller was 18.98 miles and participants typically did each type of internet activity at least once a month.

Table 1
Descriptive statistics.

	Mean (or percentage)	SD	Min	Max
Socio-demographics				
Age	48.93	17.85	16.00	92.00
Gender (male = 1)	45.45%			
Household size	2.55	1.32	1.00	7.00
Income (£)	15862.00	13896.22	0.00	144,000.00
Higher education (≥undergraduate degree = 1)	34.02%			
Driving licence (own = 1)	75.15%			
Work (work = 1)	53.96%			
Attitudes towards transport modes				
Walking/using public transport/driving for regular journey is something I like (1: strongly disagree – 5: strongly agree)				
Walking	3.87	1.22	1.00	5.00
Public transport	3.02	1.28	1.00	5.00
Driving	3.44	1.51	1.00	5.00
Numeracy and financial literacy				
Numeracy				
Not at all confident	2.27%			
Not very confident	8.14%			
Quite confident	37.68%			
Very confident	51.91%			
Financial literacy				
No correct answer	9.38%			
1 correct answer	18.18%			
2 correct answers	33.14%			
3 correct answers	39.30%			
Maths literacy	6.42	1.39	2.00	8.00
Instrumental variables				
Computer skill1 (fix)	2.28	1.11	1.00	4.00
Computer skill2 (creative)	2.57	1.20	1.00	4.00
Dependent variables				
Total travel distance (mile)	18.98	45.24	0.04	786.00
Frequency of Internet use	15.08	8.60	1.00	31.00
Sample size	1364			

3.2. Analytical model

Fig. 1 shows the relationship between *Maths Literacy, Internet Use* and total travel distance per traveller based on empirical evidence. To examine their relationships, we adopted a Bayesian approach and jointly modelled *Internet Use* and total travel distance with IVs (e.g., *Computer Skills*). The Bayesian approach allows a straightforward interpretation of the credible interval (i.e., the interval within which the estimate has a specific probability of lying. It is a philosophically different concept from that of the confidence interval) and flexibility in modelling complexities (e.g., it is easy to set up correlation matrices). While a frequentist approach uses only data for the estimation, a Bayesian approach uses prior information about the estimates (e.g., those from previous studies) based on Bayes' theorem as well as data to estimate coefficients. It is worth noting that, with the Bayesian approach, the influence of priors on estimates reduces as the sample size increases.

Specifically, we assumed *Internet Use* to be a function of socio-demographic factors, *Maths Literacy* and *Computer Skills*, while total travel distance per traveller is a function of socio-demographic factors, *Maths Literacy* and *Internet Use*. The model can be written as follows:

$$\begin{pmatrix} y_i \\ X_{Interneti} \end{pmatrix} \sim N\left(\begin{pmatrix} \alpha + \beta_{SD}^{\mathrm{T}} X_{SDi} + \beta_{ML} X_{MLi} + \beta_{Internet} X_{Interneti} \\ \gamma + \gamma_{SD}^{\mathrm{T}} X_{SDi} + \gamma_{ML} X_{MLi} + \gamma_{IV}^{\mathrm{T}} X_{IVsi} \end{pmatrix}, \begin{pmatrix} \sigma_y^2 & \rho\sigma_y\sigma_{X_{Internet}} \\ \rho\sigma_y\sigma_{X_{Internet}} & \sigma_{X_{Internet}}^2 \end{pmatrix}\right), \text{ for } i = 1, \cdots, n \quad (1)$$

where y is the total travel distance per traveller, and X_{SDi}, X_{MLi}, $X_{Interneti}$ and X_{IVsi} represent socio-demographic factors, *Maths Literacy, Internet Use* and the instrumental variables, respectively. If $\rho \neq 0$, it implies that there is an effect of endogeneity. We also conducted a Hausman-Wu test to confirm endogeneity (Hill et al., 2018). For the analyses, we assumed non-informative priors for all parameters. This means that we do not have knowledge about the parameters before seeing the data, so priors will have little impact on the parameter estimates. Further details about a Bayesian approach to travel behaviour analyses can be found in Hong et al. (2014). We took a log and square-root transformation for y and $X_{Internet}$, respectively, because y has a skewed distribution and $X_{Internet}$ has only positive values. R and Winbugs (R2WinBUGS) were used for our analyses. Several examples of code in R and Winbugs for Bayesian modelling can be found in Gelman and Hill (2007).

4. Results

The results of the joint model of internet use and total travel distance per traveller are shown in Table 2[1]. Since we adopted a Bayesian approach, we report the 95% credible interval (CI), which is analogous to the confidence interval produced by frequentist methods. 95% CI means that the estimate falls within this interval with a 95% probability (i.e., statistically significant at the $p < 0.05$ level if zero is not included).

[1] We also ran a joint model with only significant variables that were significant in the Internet use or total travel distance models. The results are shown in Appendix, and they are consistent.

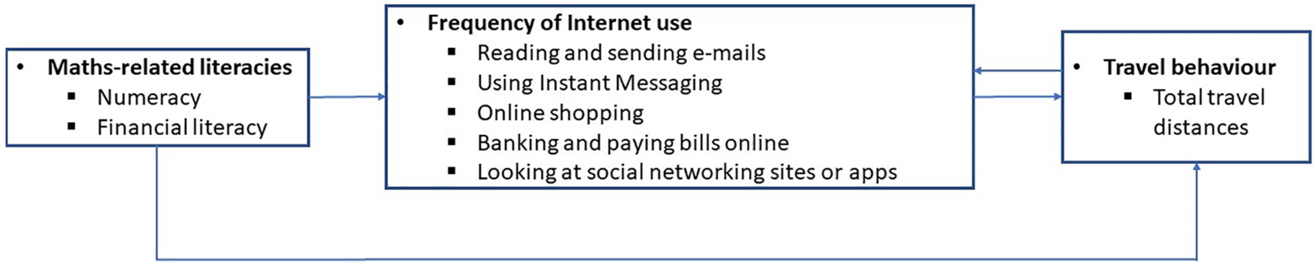

Fig. 1. Relationship between Maths-related literacies, internet use and travel behaviour.

Table 2
Results from a joint model of Internet use and total travel distance per traveller.

	Internet use			Total travel distance		
	Mean	SD (95% CI)		Mean	SD (95% CI)	
Intercept	3.38	0.07	(3.25, 3.52)	1.03	0.23	(0.61, 1.50)
Socio-demographics						
Age	−0.38	0.03	(−0.44, −0.31)	0.05	0.06	(−0.07, 0.17)
Gender (male = 1)	−0.40	0.05	(−0.50, −0.31)	−0.04	0.07	(−0.19, 0.10)
Household size	0.03	0.03	(−0.02, 0.08)	−0.01	0.04	(−0.07, 0.07)
Income (£)	0.04	0.03	(−0.01, 0.10)	0.05	0.04	(−0.03, 0.14)
Higher education (≥undergraduate degree = 1)	0.19	0.05	(0.08, 0.29)	0.09	0.08	(−0.07, 0.25)
Driving licence (own = 1)	0.32	0.08	(0.17, 0.47)	0.45	0.11	(0.23, 0.67)
Work (work = 1)	0.22	0.06	(0.10, 0.33)	0.35	0.09	(0.17, 0.51)
Attitudes towards transport modes						
Walking/using public transport/driving for regular journey is something I like (1: strongly disagree – 5: strongly agree)						
Walking	−0.03	0.02	(−0.08, 0.01)	0.01	0.04	(−0.06, 0.09)
Public transport	0.02	0.02	(−0.03, 0.07)	0.01	0.04	(−0.06, 0.08)
Driving	0.00	0.03	(−0.06, 0.06)	0.08	0.05	(−0.01, 0.17)
Maths literacy (numeracy and financial literacy)						
Maths Literacy	0.09	0.03	(0.03, 0.14)	0.11	0.04	(0.03, 0.18)
Instrumental variable						
Computer skill1 (fix)	0.23	0.03	(0.16, 0.30)			
Computer skill2 (creative)	0.55	0.04	(0.48, 0.63)			
Internet use						
Internet Use				0.14	0.06	(0.01, 0.27)
ρ	−0.06	0.05	(−0.16, 0.04)			
$\sigma_{X_{Internet}}$	0.85	0.02	(0.82, 0.89)			
σ_y				1.27	0.03	(1.22, 1.32)
R^2	0.64			0.12		
Wald test (irrelevance)	275.75	p = 0.00				
Sargan test (validity)	0.025	p = 0.87				
Hausman-Wu test	1.42	p = 0.23				

Statistically significant at the $p < 0.05$ level if zero is not included.

The results of the socio-demographic factors are consistent with those of previous studies. Age was negatively associated with the frequency of different types of internet use. Age is one of the main determinants of internet use, whereby older adults are less likely to use the internet than young adults (Office for National Statistics, 2018). Men did different types of internet activities less frequently than women. In addition, people who had a higher degree used the internet more frequently than those who did not. Holding a valid driving licence was positively associated with the frequency of internet use, and those in employment participated in internet activities more frequently than non-workers. None of the attitudinal factors showed a significant relationship with the frequency of internet use, while *Maths Literacy* was positively associated with the frequency of internet use. This implies that people with better numeracy and financial literacy skills use the internet more frequently than those with poorer skills, even when controlling for other factors, including educational level. This is consistent with previous studies, which show the importance of literacies to the frequent use of the internet (Jensen et al., 2010). James et al. (2013) also showed that frequent internet use is associated with better decision making, implying that the digital divide due to the lack of literacies potentially affects quality of life.

Finally, *Computer Skills* had significantly positive relationships with the frequency of internet use, implying that people who are confident about their computer-related skills use the internet more frequently. As mentioned, we conducted a Wald test (irrelevance) and a Sargan test (validity) to test the validity of IVs. Specifically, the Wald test examines whether IVs are strongly associated with our endogenous variable (i.e., *Frequency of Internet Use*) by comparing models with and without IVs (null hypothesis: instruments are irrelevant). The Sargan test examines whether IVs are uncorrelated with the residuals from the total travel distance model (null hypothesis: instruments are valid). The results showed that our IVs passed both tests, indicating that they were valid for the analysis. The R^2 of the Internet use model indicated that 64% of the variation can be explained by our model.

Two socio-demographic factors showed very significant associations with total travel distance per traveller, and these results are consistent with those of previous studies from Scotland (Hong and Thakuriah, 2016, 2018). First, people with a valid driving licence tended to travel further than those without a licence. This may reflect the importance of private car access in determining total travel distance. Second, people in employment travelled further than those who were not working. Given the importance of commuting as a component of all daily trips, this outcome is to be expected.

Maths Literacy showed a very positive association with total travel distance per traveller. That is, people with a better understanding of numeracy and financial literacy tended to travel further in total than people with a poorer understanding, when controlling for other factors, including educational level and income. Parsons and Bynner (2005) showed that people who have a low level of numeracy tend to have unskilled jobs and are more likely to be depressed than those with competent literacies. This result is consistent with findings from earlier studies (Axisa et al., 2012; Titheridge and Hall, 2006; Roshanaei-Moghaddam et al., 2009), which revealed the negative relationship between low-skilled jobs and commuting distances, and the positive association between depression and a sedentary lifestyle.

Our model showed that the frequency of internet use for different activities was positively associated with total travel distance per traveller. Similar to other studies (Mokhtarian and Tal, 2013; Wang and Law, 2007; Hong and Thakuriah, 2016), the result implies that the complementary association between *Internet Use* and total travel distance outweighs its substitutional association. Our model also identified *Maths Literacy* as having a direct association with total travel distance as well as an indirect association through *Internet Use*. This result raises the possibility that the lack of numeracy and financial literacy skills could exacerbate social exclusion impacts in the digital age.

Finally, ρ was not statistically significantly different from zero in our model, implying that there was no serious effect of endogeneity between the frequency of internet use for the various activities and total travel distance per traveller. We also conducted a Hausman-Wu test (exogeneity) to examine the relationship between the residuals from the Internet use model and total travel distance. This gave a value of $p = 0.26$, meaning the null hypothesis (no endogeneity) could not be rejected, so we re-ran our model constraining ρ to a value of 0. The results (Table 3) were highly consistent with the previous ones: *Maths Literacy* still showed significant positive associations with the frequency of internet use and total travel distance per traveller while controlling for other factors, including education and income levels.

5. Conclusions

ICT has become an essential part of our daily lives in the digital age, and can be employed as a tool for improving accessibility in the world today, in its broadest sense. In particular, it could support people who are socially excluded due to their mobility constraints. However, it could also aggravate the social exclusion of already marginalised people who lack either resources or the literacies and competencies that are closely related to ICT use as well as travel behaviour. Our present research examined the comprehensive relationship between maths-related literacies of numeracy and financial literacy (embedded within the wider UNESCO lifewide literacy conception), the frequency of internet use for several activities, and travel behaviour.

Before discussing the main implications of our findings, we must acknowledge the limitations of this research. First, our measure of internet use only considered the frequency of the five main online activities, and these were given an equal weight when we derived the summary variable. A more accurate measure of internet use for diverse activities and its connections with different types of travel behaviour need to be considered in future research to improve our understanding. Second, our composite measure of *Maths Literacy* is somewhat simplistic. Future studies could focus on how to combine these two variables in a more informative way, perhaps with existing maths achievement scores, and/or maths measures embedded in employment contexts. Lastly, our use of a self-reported one-day travel diary recalling activity on the previous day could limit our analysis, given that studies have found that people often ignore short trips, especially those involving walking and cycling, when reporting their trip information during the survey (Hong et al., 2018, Stopher et al., 2007). GPS data could be used to capture mis-reported trips in future research.

Our findings provide several research and policy implications. First, our results revealed that maths-related literacies were significantly associated with the frequency of internet use, whereby people with a higher level of maths-related literacies (i.e., numeracy and financial literacy) used the internet more often for online activities, even when the analysis controlled for prior educational level. This result shows the importance of maths competencies for accomplishing key life activities in the digital age. ICT competence has become a key life skill, equipping people to access a range of services they would not otherwise be able to use. For example, people may not be able to travel but, through ICT, can still participate in activities such as shopping, working or communicating with their friends. This provides a new opportunity to make society more inclusive. However, we found that this benefit would not be available to those who lack basic maths-related literacies, which could lead to their greater social exclusion.

Second, maths-related literacies also have a significant association with total travel distance per traveller. In other words, people with higher levels of maths-related literacies travel further overall than those with lower literacy levels. It implies that they are more likely to be socially included, regardless of personal circumstances (e.g., income, driving licence ownership and employment status) and attitudes towards different transport modes. Based on previous studies showing the effects of mobility-based accessibility on social exclusion, as well as mobility on well-being (Stanley et al., 2011; Currie and Delbosc, 2010), our findings imply that a strong policy aim of improving maths-related literacies could be successful at mitigating effects of social exclusion, while providing additional benefits of improving mobility and, potentially, well-being.

Third, our research highlights the importance of literacies on travel behaviour, beyond the importance of educational level and income. Extensive previous research has emphasized the role of education and income, but not literacies, specifically maths-related literacies, on travel outcomes. We found that such literacies do indeed relate to the frequency of internet use for several activities, and travel behaviour, even after controlling for educational level, work status and income. Hence, our work fills a knowledge gap, thereby providing a more comprehensive understanding of the determinants of travel behaviour.

Finally, we found a complementary association between the frequency of internet use and total travel distance. Specifically, people who used the internet more often travelled further overall. This supports the findings of previous studies that highlight the importance of considering ICT impacts on future travel demand. Combined with the above results, we also found that maths-related literacies were directly associated with total travel distance as well as being indirectly associated with travel behaviour through internet use. This calls for further research on the ICT and travel behaviour analysis considering different measures of literacies and their complicated connections with travel behaviour.

In conclusion, the present research found important relationships between maths-related literacies, the frequency of internet use, and travel behaviour. This work further calls for greater use of interdisciplinary working to merge frameworks from academic research backgrounds with transport and educational planners, as well as engage with local government, national government and international organisations such as UNEESCO-UIL, the Pascal International Observatory and think tanks involved in achieving Sustainable Development Goals (especially SDG4 on inclusive eduation for all). As outlined here, empirical work on lifewide literacy, particularly maths and digital marginalisation, will only widen social inequalities, particularly in a post-COVID-19 world increasingly pushed to engage in and understand a digital reality (including the data informing such digital practices). The current COVID-19 crisis has restricted physical mobilities, and therefore uncovered critical vulnerabilities to digital *exclusion*. As the world returns to more normal patterns of physical travel, we urge that our

Table 3
Results from a joint model of Internet use and total travel distance per traveller ($\rho = 0$).

	Internet use			Total travel distance		
	Mean	SD (95% CI)		Mean	SD (95% CI)	
Intercept	3.38	0.07	(3.24, 3.52)	1.24	0.15	(0.93, 1.53)
Socio-demographics						
Age	−0.38	0.03	(−0.45, −0.31)	−0.01	0.05	(−0.11, 0.09)
Gender (male = 1)	−0.40	0.05	(−0.50, −0.30)	−0.07	0.07	(−0.20, 0.07)
Household size	0.03	0.03	(−0.02, 0.08)	−0.01	0.04	(−0.08, 0.07)
Income (£)	0.04	0.03	(−0.01, 0.10)	0.06	0.04	(−0.02, 0.14)
Higher education (≥ undergraduate degree = 1)	0.19	0.05	(0.08, 0.30)	0.11	0.08	(−0.05, 0.26)
Driving licence (own = 1)	0.32	0.07	(0.17, 0.45)	0.48	0.11	(0.27, 0.69)
Work (work = 1)	0.21	0.06	(0.11, 0.34)	0.36	0.08	(0.21, 0.53)
Attitudes towards transport modes						
Walking/using public transport/driving for regular journey is something I like (1: strongly disagree – 5: strongly agree)						
Walking	−0.03	0.02	(−0.08, 0.01)	0.01	0.04	(−0.06, 0.08)
Public transport	0.02	0.03	(−0.03, 0.07)	0.01	0.04	(−0.06, 0.08)
Driving	0.00	0.03	(−0.06, 0.06)	0.08	0.04	(−0.01, 0.16)
Maths literacy (numeracy and financial literacy)						
Maths Literacy	0.08	0.03	(0.03, 0.14)	0.12	0.04	(0.05, 0.20)
Instrumental variable						
Computer skill1 (fix)	0.23	0.04	(0.16, 0.30)			
Computer skill2 (creative)	0.55	0.04	(0.48, 0.62)			
Internet use						
Internet Use				0.07	0.03	(0.01, 0.15)
$\sigma_{X_{Internet}}$	0.85	0.02	(0.82, 0.89)			
σ_y				1.27	0.02	(1.22, 1.32)
R^2	0.64			0.13		

Statistically significant at the $p < 0.05$ level if zero is not included.

findings be taken into consideration by educational policy-makers, digital creators and other stake-holders to promote capacity-building in the areas of financial literacy, numeracy and digital competences, as resources for combatting the further widening of social inequalities globally.

6. Geolocation information

Glasgow, Scotland, United Kingdom.

CRediT authorship contribution statement

Jinhyun Hong: Conceptualization, Formal analysis, Writing - original draft. **Piyushimita (Vonu) Thakuriah:** Conceptualization, Writing - review & editing. **Phil Mason:** Conceptualization, Writing - review & editing. **Catherine Lido:** Conceptualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank the Urban Big Data Centre at the University of Glasgow for sharing the iMCD data. The work was supported by the Economic and Social Research Council (grant numbers ES/L011921/1, ES/S007105/1).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tbs.2020.07.007.

REFERENCES

Adult Education Survey, 2015. Reference Metadata, Eurostat [Online]. Available: http://ec.europa.eu/eurostat/cache/metadata/en/trng_aes_12m0_esms.htm [Accessed 27th, June 2018].
Andreev, P., Salomon, I., Pliskin, N., 2010. Review: state of teleactivities. Transp. Res. C: Emerg. Technol. 18, 3–20.
Axisa, J.J., Scott, D.M., Bruce Newbold, K., 2012. Factors influencing commute distance: a case study of Toronto's commuter shed. J. Transp. Geogr. 24, 123–129.
Ben-Elia, E., Lyons, G., Mokhtarian, P.L., 2018. Epilogue: the new frontiers of behavioral research on the interrelationships between ICT, activities, time use and mobility. Transportation 45, 479–497.
Bris, M., Pawlak, J., Polak, J.W., 2017. How is ICT use linked to household transport expenditure? A cross-national macro analysis of the influence of home broadband access. J. Transp. Geogr. 60, 231–242.
Burchardt, T., le Grand, J., Piachaud, D., 1999. Social exclusion in Britain 1991–1995. Social Policy Admin. 33, 227–244.
Bynner, J., Parsons, S., 2001. Qualifications, basic skills and accelerating social exclusion. J. Educ. Work 14, 279–291.
Cao, X.J., Xu, Z., Douma, F., 2012. The interactions between e-shopping and traditional in-store shopping: an application of structural equations model. Transportation 39, 957–974.
Carpentieri, J.D., Litster, J., Frumkin, L., 2009. Adult Numeracy: A Review of Research. National Research and Development Centre for Adult Literacy and Numeracy, London.
Chiswick, B.R., Lee, Y.L., Miller, P.W., 2003. Schooling, literacy, numeracy and labour market success. Econ. Rec. 79, 165–181.
Choo, S., Lee, T., Mokhtarian, P., 2007. Do transportation and communications tend to be substitutes, complements, or neither? Transp. Res. Rec. 2010, 121–132.
Currie, G., Delbosc, A., 2010. Modelling the social and psychological impacts of transport disadvantage. Transportation 37, 953–966.
De Abreu E Silva, J., Melo, P.C., 2018. Home telework, travel behavior, and land-use patterns: a path analysis of British single-worker households. J. Transp. Land Use, 11.
De Haan, J., 2004. A multifaceted dynamic model of the digital divide. IT&Society, 1, 66–88.
Department for Business Innovation & Skills, 2012. National Adult Learning Survey 2010. BIS Research Paper 63. UK, London.
Gelman, A., Hill, J., 2007. Data Analysis Using Regression and Multilevel/Hierarchical Models. Cambridge University Press, New York.
Ghazal, S., Cokely, E.T., Garcia-Retamero, R., 2014. Predicting biases in very highly educated samples: numeracy and metacognition. Judgment Decision Making 9, 15–34.
Golob, T.F., Regan, A.C., 2001. Impacts of information technology on personal travel and commercial vehicle operations: research challenges and opportunities. Transp. Res. C: Emerg. Technol. 9, 87–121.
Green, A.E., Owen, D., 2006. The Geography of Poor Skills and Access to Work. Joseph Rowntree Foundation.
Hill, R.C., Griffiths, W.E., Lim, G.C., 2018. Principles of Econometrics. Wiley.
Hodgson, F.C., Turner, J., 2003. Participation not consumption: the need for new

participatory practices to address transport and social exclusion. Transp. Policy 10, 265–272.
Hong, J., Mcarthur, D., 2017. How does internet usage influence young travelers' choices? J. Plann. Educ. Res. 0739456X17736811.
Hong, J., Shen, Q., Zhang, L., 2014. How do built-environment factors affect travel behavior? A spatial analysis at different geographic scales. Transportation 41, 419–440.
Hong, J., Sila-Nowicka, K., McArthur, D.P., 2018. Is the popularity of social networking services beneficial for public health? Focusing on active travel and BMI. J. Transp. Heal.
Hong, J., Thakuriah, P., 2016. Relationship between motorized travel and time spent online for nonwork purposes: an examination of location impact. Int. J. Sustain. Transp. 10, 617–626.
Hong, J., Thakuriah, P.V., 2018. Examining the relationship between different urbanization settings, smartphone use to access the Internet and trip frequencies. J. Transp. Geogr. 69, 11–18.
Ipsos MORI, 2015. iMCD survey technical report.
James, B., Boyle, P., Yu, L., Bennett, D., 2013. Internet use and decision making in community-based older adults. Front. Psychol. 4.
Jensen, J.D., King, A.J., Davis, L.A., Guntzviller, L.M., 2010. Utilization of internet technology by low-income adults: the role of health literacy, health numeracy, and computer assistance. J. Aging Heal. 22, 804–826.
Kenyon, S., 2010. The impacts of Internet use upon activity participation and travel: results from a longitudinal diary-based panel study. Transp. Res. C: Emerg. Technol. 18, 21–35.
Kim, S.-N., 2017. Is telecommuting sustainable? An alternative approach to estimating the impact of home-based telecommuting on household travel. Int. J. Sustain. Transp. 11, 72–85.
Lido, C., Reid, K., Osborne, M., 2019. Lifewide learning in the city: novel big data approaches to exploring learning with large-scale surveys, GPS, and social media. Oxford Rev. Educ. 45, 279–295.
Lucas, K., 2012. Transport and social exclusion: where are we now? Transp. Policy, 20, 105–113.
Lucas, K., 2013. Transport and social exclusion. In: Rodrigue, J., Notteboom, T., Shaw, J. (Eds.), The SAGE handbook of Transport Studies, SAGE Publications Ltd, London.
Lusardi, A., Mitchell, O., Curto, V., 2010. Financial literacy among the young. J. Consumer Affairs 44, 358–380.
Lusardi, A., Mitchell, O.S., 2014. The economic importance of financial literacy: theory and evidence. J. Econ. Literature 52, 5–44.
Mokhtarian, P., 2003. Telecommunications and travel: the case for complementarity. J. Indust. Ecol. 6, 43–57.
Mokhtarian, P., Salomon, I., Handy, S.L., 2006. The Impacts of ICT on leisure activities and travel: a conceptual exploration. Transportation 33, 263–289.
Mokhtarian, P., Tal, G., 2013. Impacts of ICT on travel behavior: a tapestry of relationships. In: Rodrigue, J., Notteboom, T., Shaw, J. (Eds.), The SAGE Handbook of Transport Studies, SAGE Publications Ltd.
OFCOM 2017. Communications Market Report: Scotland.
Office for National Statistics, 2018. Internet users, UK: 2018 -Internet use in the UK annual estimates by age, sex, disability and geographical location.
Parsons, S., Bynner, J., 2005. Does Numeracy Matter More. National Research and Development Centre for Adult Literacy and Numeracy.
Peter, E., Hibbard, J., Slovic, P., Dieckmann, N., 2007. Numeracy skill and the communication, comprehension, and use of risk-benefit information. Health Aff. 26, 741–748.
Peter, J., Valkenburg, P.M., 2006. Adolescents' internet use: testing the "disappearing digital divide" versus the "emerging digital differentiation" approach. Poetics 34, 293–305.
Roshanaei-Moghaddam, B., Katon, W.J., Russo, J., 2009. The longitudinal effects of depression on physical activity. Gen. Hosp. Psychiatry 31, 306–315.
Skagerlund, K., Lind, T., Strömbäck, C., Tinghög, G., Västfjäll, D., 2018. Financial literacy and the role of numeracy–how individuals' attitude and affinity with numbers influence financial literacy. J. Behav. Experiment. Econ. 74, 18–25.
Stanley, J., Stanley, J., Vella-Brodrick, D., Currie, G., 2010. The place of transport in facilitating social inclusion via the mediating influence of social capital. Res. Transp. Econ. 29, 280–286.
Stanley, J.K., Hensher, D.A., Stanley, J.R., Vella-Brodrick, D., 2011. Mobility, social exclusion and well-being: exploring the links. Transp. Res. A: Policy Pract. 45, 789–801.
Stopher, P., Fitzgerald, C., Xu, M., 2007. Assessing the accuracy of the Sydney Household Travel Survey with GPS. Transportation 34, 723–741.
Thakuriah, P., Sila-Nowicka, K., Hong, J., Boididou, C., Osborne, M., Lido, C., McHugh, A., 2020. Integrated Multimedia City Data (iMCD): a composite survey and sensing approach to understanding urban living and mobility. Comput. Environ. Urban Syst. 80, 101427.
Titheridge, H., Hall, P., 2006. Changing travel to work patterns in South East England. J. Transp. Geogr. 14, 60–75.
UNESCO, 2004. Manual for Developing Literacy and Adult Education Programmes in Minority Language Communities. UIL, Bangkok.
van den Berg, P., Arentze, T., Timmermans, H., 2013. A path analysis of social networks, telecommunication and social activity–travel patterns. Transp. Res. C: Emerg. Technol. 26, 256–268.
van Wee, B., Geurs, K., Chorus, C., 2013. Information, communication, travel behavior and accessibility. J. Transp. Land Use 6, 1–16.
Wang, D., Law, F.Y.T., 2007. Impacts of Information and Communication Technologies (ICT) on time use and travel behavior: a structural equations analysis. Transportation 34, 513–527.
Zhou, Y., Wang, X., 2014. Explore the relationship between online shopping and shopping trips: an analysis with the 2009 NHTS data. Transp. Res. A: Policy Pract. 70, 1–9.
Zhu, P., 2012. Are telecommuting and personal travel complements or substitutes? Ann. Reg. Sci. 48, 619–639.
Zhu, P., Wang, L., Jiang, Y., Zhou, J., 2018. Metropolitan size and the impacts of telecommuting on personal travel. Transportation 45, 385–414.