Travel-based multitasking: review of the role of digital activities and connectivity

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Travel-based multitasking, also referred to as travel time use, is now a well-established concept, whose existence is supported by the technological trajectories, with mobile information and communication technologies (ICT) and vehicle automation working together to allow travel time to be more productive and enjoyable. Despite existence of reviews of travel-time multitasking studies, the systematic overview of the role digital activities, i.e. those that necessarily require modern ICT equipment to participate, has been limited, often wrapped under the umbrella term 'use of ICT', potentially obscuring their complexity and sophistication. Similarly, the role of connectivity and its attributes, e.g. speed (bandwidth), reliability, price, ease of use, data allowance or security, deserves a more systematic overview given its key role in enabling digital online activities and hence the travel-based multitasking options. This paper provides a review of 77 empirical travel-based multitasking-studies that explored the role of digital activities or connectivity. In particular, the review discusses the existing typologies of digital activities, dividing them into hardware-centric, function-centric or a combination of both (mixed). Subsequently, key contributions are discussed with respect to treatment of digital activities and connectivity and its attributes. Based on the review, it is possible to observe that the existing studies have looked only at a handful of rather restricted online activities that do not sufficiently capture the sophistication with which individuals interact with the virtual world nowadays. Furthermore, the role of connectivity, although deeply embedded in the 'C' of the 'ICT' concept, has not been looked at or modelled in any detail in studies related to travel time use or its quality. This existing shortcoming might have resulted in the insufficient understanding of the mechanisms driving travel time use, the associated experience indicators of customer satisfaction, productivity or the consequences for relative attractiveness of transport modes. All of these considerations remain, however, crucial for designing, appraising and operating transport infrastructure and services that are able to take the advantage of lifestyle digitisation to meet the increasing customer needs while also delivering broader economic, social benefits and possibly also environmental benefits.

Keywords: connectivity; ICT; digital activities; online activities; multitasking; travel time use

1. Introduction

The opportunity of using travel time for productive and enjoyable purposes, also termed travel-based multitasking or worthwhile use of travel time, has recently undergone another wave of increased attention from researchers, policy makers and the public. The interest has been fuelled, at least to an extent, by the emerging role of mobile Information and Communication Technologies (ICT) since the mid-2000s, enabling widespread participation in digital activities (Lyons & Urry, 2005). The most recent interest, however, appears to have been due also to a combination of the technological progress in vehicle automation (Pudāne, Molin, Arentze, Maknoon, & Chorus, 2018) and the growing role of connectivity in the delivery of on-board digital activities[1]. The latter aspect is related to a more general technological trend whereby services provided by applications on the devices depend on access to online resources (data, storage, processing power) and thus on reliable and high bandwidth connectivity.

In line with this trend, provision of connectivity to passengers seems to have evolved from being a luxury to becoming almost a necessity. For example, in the UK, the train operating companies (TOCs) are now obliged to provide, as part of their franchise agreements, free on-board Wi-Fi to their passengers (House of Commons, 2017). This not different from other operators across the world who have been exploring the availability of connectivity for passengers in order to improve journey satisfaction and productivity (Dong, Mokhtarian, Circella, & Allison, 2015; Tang, Zhen, Cao, & Mokhtarian, 2018). Even airlines now increasingly provide on-board connectivity, the role of which has grown to the extent that Federal Aviation

[1] For the purpose of the current paper, digital activities are interpreted as those activities which necessarily require modern ICT equipment to participate.

Administration (FAA) now allow use of mobile devices and Wi-Fi during all phases of flight, including take-off and landing (FAA, 2017; Schwieterman, Schulz, Kohls, & Boggess, 2014). Lastly, the evolution of the concept of an *Autonomous Vehicle* (AV) to a *Connected and Autonomous Vehicle* (CAV) highlights acknowledgment of the key role of connectivity, both in the safe and efficient operation of these vehicles, and in enabling an enjoyable and productive environment on-board. Although how, when or even whether CAVs will become the mainstream of transport systems remains a contentious debate, within this debate the importance of connectivity is largely indisputable given how dependent CAV designs or postulated benefits from travel time use are on it.

All of this cumulates to a substantial body of evidence that the ability to engage in digital activities is an increasingly important determinant of productivity while travelling, and thus of the on-board experience and overall travel satisfaction. This, in turn, translates into implications for the relative attractiveness of particular modes of transport, with the ultimate potential to affect modal split or travel amount and ridership. For example, a recent survey in the UK concerning value attached by rail passengers to faster or more reliable Internet access put the willingness to pay for improved connectivity at between 7 and 26 percentage of the fare, depending on the purpose and length of journey (SDG, 2016). Turning this finding around means that free provision or enhancements of such services on-board, which is increasingly expected by transport users, as well as enshrined in transport policies, may translate into a reduced generalised cost of travel. This hypothesis is supported by the recent findings of Wardman, Chintakayala, & Heywood (2019) who reported that worthwhile use of travel time in rail context, including participation in digital activities, was associated with reduced value of travel time savings (VTTS) and thus with an increased demand for rail

travel. Their findings suggested that inability to use mobile devices while travelling would translate into 13.2 and 9% lower demand for rail travel (within their sample) for commuting and other purposes respectively. A broadly similar set of conclusions concerning the role of travel time activities was obtained by Molin, Adjenughwure, de Bruyn, Cats, & Warffemius (2020). The authors found that depending on the activity and purpose of travel the respondents had a value of travel time (VOT)[2] lower by between 10.7 and 47.1% as a result of conducting activities while travelling as compared to contexts in which such activities could not be undertaken. With respect to connectivity Bounie, Adoue, Koning, & L'Hostis (2019) reported that public transport users would see the reduction of their subjective value of travel time by 12% if they could benefit from optimal connectivity. The associated continuing debate concerning suitability of the value of travel time savings as a measure of benefit from transport investments inspired the recent 'Zero Value of Time Roundtable' organised by the OECD's International Transport Forum (ITF). The debate concluded that while travel time savings should continue to form part of the rationale for investments in transport infrastructure, there is also a growing case for interventions that improve quality of travel time, including via enablement of ICT use and participation in digital activities (ITF, 2019).

To what extent these changes in the nature of travel time are considered against the traditional transport modelling considerations (duration, monetary cost, reliability) remains debatable, however. In light of the above evidence and increasing importance,

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[2] We follow the respective authors' use of the concepts of VTTS and VOT. For a more detailed discussion of those, we refer the reader to Jara-Díaz (2007) and Mackie, Jara-Díaz, & Fowkes (2001).

the topic of on-board digital activities and the role of connectivity clearly deserve continuing research attention.

Over the past two decades, the phenomenon of travel-based multitasking has been researched extensively, as has been summarised in a number of papers to-date (Keseru & Macharis, 2018; Pawlak, 2014; Pawlak, Le Vine, Polak, Sivakumar, & Kopp, 2015; Pawlak, Polak, & Sivakumar, 2017; M. Russell et al., 2011; SDG, 2016; Timmermans & Van der Waerden, 2008; Watts & Urry, 2008). In particular, the recent review by Keseru and Macharis (2018) provided a comprehensive overview of the existing travel-based multitasking studies, focusing on their data collection approaches, reported factors associated with particular multitasking behaviours and proposing a future research agenda. Nonetheless, to date the treatment of digital activities in the review papers has been limited, often wrapped under the umbrella term 'use of ICT', potentially obscuring their complexity and sophistication. Similarly, the role of connectivity deserves a more systematic overview given its role in expanding the travel-based multitasking options. The present contribution aims to address those shortcomings and hence complement the existing efforts at mapping the state of travel-based multitasking research domain. To address this aim, the current paper has the following objectives:

- to examine and systematise the existing activity typology conventions for the travel-based digital activities encountered in the literature;
- to review the treatment of digital activities in the existing empirical studies concerning travel-based multitasking;
- to explore the treatment of connectivity and its attributes in those studies, including its speed (bandwidth), reliability, price, ease of use, data allowance,

and security;

- to provide a critical discussion concerning state of the domain of travel-based multitasking with respect to understanding of the role of digital activities and connectivity.

The paper is structured as follows. Section 2 outlines methodology of the review, Section 3 looks at the empirical studies concerning digital activities, while section 4 examines the role of connectivity and its attributes. The final section 5 discusses state of the domain and concludes the paper. The list of identified studies, systematised by the typologies of activities and treatment of connectivity, is included in Appendix 1.

2. The review approach

The review took as its starting point literature referred to in a number of publications covering the topic (Keseru & Macharis, 2018; Pawlak, 2014; Pawlak, Le Vine, et al., 2015; Pawlak et al., 2017; M. Russell et al., 2011; SDG, 2016; Timmermans & Van der Waerden, 2008; Watts & Urry, 2008), particularly the review by Keseru and Macharis (2018). The initial list compiled in this manner was enhanced by searching via Google Scholar and ScienceDirect for studies, published in English, containing terms 'travel time use', 'travel-based multitasking' and 'online activities', 'digital activities', 'connectivity', 'on-board Wi-Fi', 'ICT', and then scanning their abstracts for relevance. Studies that looked at travel time use but did not explore digital activities or connectivity were excluded, as were those that focused primarily on basic functionalities of mobile phones, i.e. voice or text communication and their implications for safety, especially in the context of driving. Similarly, the use of ICT purely for

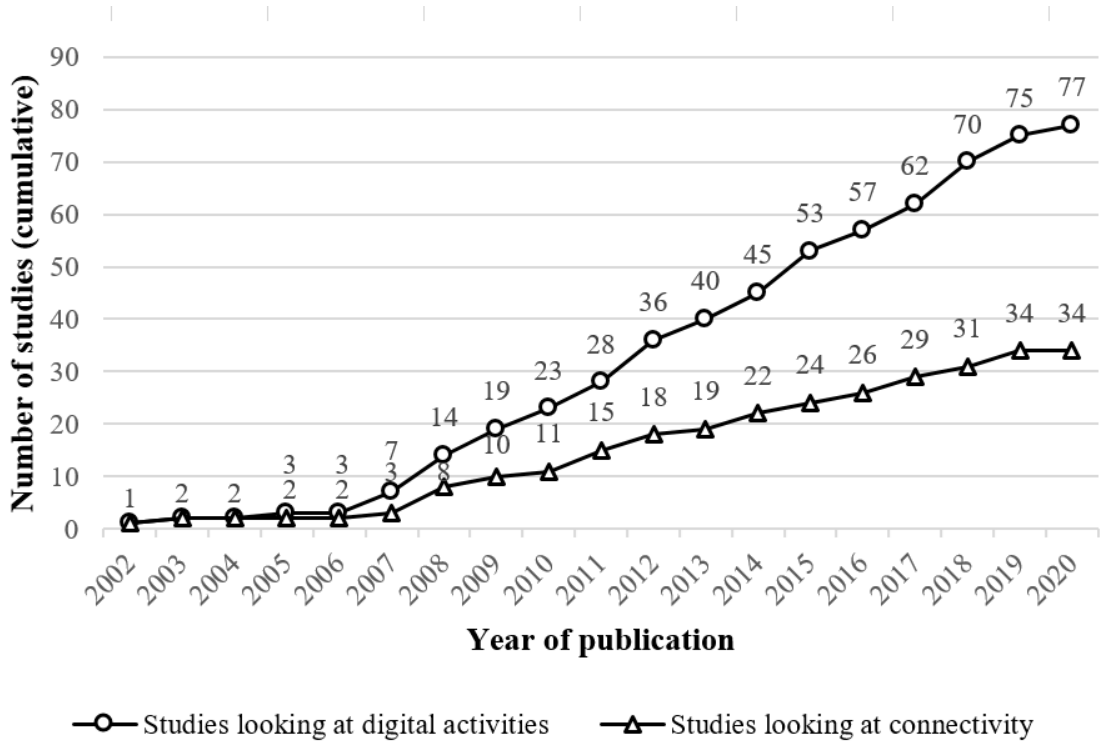


Figure 1. Existing travel-based multitasking studies looking at digital activities and connectivity: cumulative count by year of publication, from 2002 until early 2020.

travel planning or monitoring purposes, e.g. distance travelled, calories burnt, were excluded. The final list of the 77 relevant studies is available in Appendix 1, while Figure 1 presents the cumulative plot of the studies across time.

A number of initial observations can be made. Firstly, the year 2007 appears to be when the field started gaining a momentum that has since remained stable, with between four to eight studies added to the domain each year. This take-off is probably not coincidental, as at about that time mobile devices started becoming mainstream while at the same time broadband Internet became more widely available, including on-board transport modes. The second observation is that less than half of these studies looking at digital activities while travelling explicitly acknowledged the role of connectivity and its attributes. Undesirably, this gap has been growing despite the evolution in digital activities such that they have become increasingly coupled with

online resources and services, which would warrant a consistent exposition of this underlying dependency. Importantly, growth in the number of studies as shown in Figure 1 has not been distributed evenly across modes of transport or geographical contexts, which is presented in detail in Appendix 2. Rail has been by far the most studied transport mode context, followed by public transport modes (including urban bus and metro) and private motorised transport. Air travel or active modes (walk, bicycle) have been comparatively less studied. In terms of the geographical distribution, majority of the studies have been based in Europe, especially in the UK and the Netherlands. A number of studies have explored the subject in Asia, North America and Australia and Oceania while no studies have been identified in African or South American contexts. The latter observation may highlight a research gap on the one hand, but also be an outcome of the review being limited to studies reported in English, in light of prevalence of French-, Portuguese- and Spanish-speaking populations in those areas.

Existence of a sizeable amount body of empirical evidence accompanied by its significance for transport sector highlight the need for a systematic presentation of the state of the domain, which the present paper aims to achieve. Nevertheless, to remain succinct, the discussion below is focused on contributions that proposed substantially new approaches, such as survey or modelling designs, or that explored new aspects of the research problem, e.g. connectivity attributes.

3. Typology conventions for digital activities in travel-based multitasking

Digital activities in the context of travel-based multitasking, and in fact more widely in the time use literature, have remained conceptually loosely defined. In addition, the concept itself has seen its variations, e.g. tele-activities, online activities, e-activities, mobile activities, partly driven by the specific focus of a given study, and partly the

continuous evolution in the enabling technologies, e.g. the emergence of mobile ICT such as broadband Internet. Nevertheless, even within this fuzzy and evolving conceptual landscape, two broad, but not mutually exclusive, typological conventions seem to have emerged: *hardware*-centric and *function*-centric. Both are discussed below. In addition to those particular conventions, digital activities can be merged with non-digital ones to form broader activity categories, e.g. the 'working' category can capture 'using ICT to conduct work activities' as well as 'non-ICT work activities'.

The hardware-centric convention defines activities purely in reference to the specific devices (hardware), e.g. 'using a smartphone' or 'using a laptop'. This approach is particularly well suited for studies relying on observations (Gamberini et al., 2013), and seeking to understand specific device adoption, penetration or frequency of use. In addition, up until the mid-2000s, mobile devices tended to be monofunctional and thus specific types of devices could be reasonably mapped onto a particular activities, e.g. portable music player – listening to music, mobile phone – conversation or texting. More recently, however, mobile devices have become versatile, multifunctional platforms, which tends to be captured by the term 'smart'. This also implies that the same pieces of hardware might possess radically different functionalities that are enabled by their respective software, including applications ('apps'). For such devices, the hardware-centric approach might not be entirely capable of capturing the variety and sophistication of the digital activities that they are able to support. Consequently, insights into exploring drivers of satisfaction and productivity relying on the ability to conduct specific digital activities are likely to suffer from shortcomings if the hardware-centric typology is followed in its pure form (see below for a discussion of a mixed-convention). This is also reflected in the studies to date (see Appendix 1), since only a handful of studies followed this convention in its pure form.

The function-centric convention, meanwhile, focuses on the consumption of specific services or applications, e.g. ‘using e-mail’ or ‘watching a movie’. This convention more naturally captures the sophistication of digital behaviour and its evolution, and is conceptually closer to time use modelling involving activities as the basic modelling blocks. A variation of the function-centric approach involves reporting on the use of a particular piece of software or an online service or website, which respondents might identify as their digital activity. Arguably, this approach facilitates reporting by reducing the possible confusion of a respondent with respect to how they should classify use of a particular application or service into activity categories. For instance, using a web browser for journey planning could be considered ‘web browsing’ just as much as ‘journey planning’, both commonly used as digital activity categories (as will be shown in the next section). Under such circumstances, the information can even be retrieved from the device or network usage history, effectively providing a so-called ‘big data’ source for digital time use modelling. In fact, the latter is not an unusual practice among operators of public wireless networks in order to manage service quality, e.g. preventing excessive consumption, obtaining information regarding users and their preferences, or understanding demand in order to provide a sufficient service, e.g. bandwidth. Whilst this is typically done with the user’s legal consent, i.e. agreement to terms and conditions of the service use, there remain ethical concerns regarding the actual user awareness of the practices, given the evidence that the users tend not to familiarise themselves deeply with such content (Steinfeld, 2016).

In addition to the shortcomings resulting from the privacy issues, such an approach tends to lead to an unmanageable number of possible reporting categories. Furthermore, while accessible globally, the actual adoption and popularity of specific online services or software is strongly dependent on location, e.g. news services

(websites or applications) or social media platforms will typically have the content and visual design adapted to the local affairs, preferences and regulations, to make them more relevant and appealing to the users (Li & Chen, 2014; Vincos, 2018), possibly hampering direct comparability. Thus, an optimal strategy for a function-centric typology is to have activity categories accompanied by concrete and up-to-date examples of the applications and services most widespread in a specific geographical context. In this way, the clarity for respondent is combined with the comparability necessary for the research.

The two conventions, i.e. hardware- and function-centric, are not mutually exclusive, however. For instance, it is possible to define activities in terms of both hardware and software, e.g. using a smartphone to conduct business communication (cf. Frei, Mahmassani, & Frei, 2015). Such a *mixed* convention might be particularly suitable to travel time contexts, where particular devices might be inherently easier to use despite possibly an inferior quality of the digital experience. An example could be using a smartphone instead of a laptop to watch a movie while standing on a crowded train. Whereas the former would typically provide an inferior quality of watching due to the screen size, the latter would be very cumbersome to use when standing, especially within a crowd. Hence, a mixed approach might be applicable, where grounds exist for possible inter-device heterogeneity in the delivery of the digital functionality, though at the cost of a larger and more complex survey. In fact, most studies identified in the current context followed this mixed convention (see Appendix 1). Nevertheless, detailed rationale for adopting a particular convention or digital activity categorisation have been virtually absent from the studies, often appearing to be a combination of emulation of prior studies, researchers' own experience and convenience.

Finally, what tends to be almost entirely omitted from discussions concerning digital activities while travelling is the fact that a substantial set of these activities might be taking place on the devices *in the background*, often even without the user's awareness. This type of device multitasking should be clearly distinguished from conscious participation and use of multiple functionalities at the same time, possibly interleaving or overlaying, of which substantial discussion is provided by (Circella, Mokhtarian, & Poff (2012). The examples of background activities include e-mail refreshing, software updating, media caching, data backup, geolocation, or online storage synchronising. Whilst such activities might not be directly requested or involve user interaction, they can be crucial for the overall delivery of digital experience, e.g. staying up-to-date with communications or delivering uninterrupted quality of media. More importantly, those background activities will influence bandwidth and overall data consumption. These in turn can affect the quality of other activities that share the same connection, increase data consumption and, from the supply side, determine the attributes of the necessary connectivity infrastructure. Furthermore, given their operation in the background, these activities are very difficult to capture in a traditional survey, and indeed would probably require quite intrusive monitoring of the user devices and network use if they were to be identified at all comprehensively. Paradoxically, the need for user consent to allow such monitoring would increase awareness of these activities and could therefore result in different behaviour, following the Hawthorne effect (see, for example, Køster et al., 2016). Studies exploring this aspect of travel time use in relation to consumption of connectivity have been, rather surprisingly, absent from the field to date.

4. Digital activities in empirical travel-based multitasking studies

The present section seeks to highlight a number of empirical contributions concerning analysis of digital activities in the context of travel-based multitasking in order to fulfil two purposes. On the one hand, the selection should give a compact depiction of evolution of this research field and its current state with respect to the empirical knowledge. On the other, it should also demonstrate an increasing level of sophistication of the offered insights, resulting from employment of a wider range of methodological approaches for data collection and analysis as well as from establishing links to other discourses within transport discipline.

In terms of empirical studies concerning digital activities, the set of contributions from the early 2000s that analysed the UK National Rail Passenger Survey (NRPS) are among the most important (Holley, Jain, & Lyons, 2008; Lyons, Jain, & Holley, 2007; Lyons & Urry, 2005). These contributions not only reignited the debate with conceptual insight, but also provided large-scale evidence (passengers across the entire UK rail network) that effectively refuted the hypothesis that travel time use, including digital activities, is insignificant. The set of contributions started with an insightful discussion by (Lyons & Urry, 2005) that sought to relate the emerging debate on activities while travelling, including the use of ICT, in the existing transport discourses, such as travel time budget or travel time (savings) valuation. In terms of the activities that might be undertaken on a train, which was the context the authors discussed most extensively, they suggested a number that could be seen as early digital activities: playing games (electronic or otherwise), listening to music/radio, text messages/phone calls-work, text messages/phone calls-personal. In the actual empirical analysis that followed, however, using the Autumn 2004 NRPS wave (Holley et al., 2008; Lyons et al., 2007; Pawlak & Polak, 2010), only listening to music/radio was explored as a fairly crude digital activity. The authors did, however, incorporate

analysis of respondents' possession and *use* of ICT devices, including laptops, mobile phones, PDA[3]/handheld computers and personal stereo/radio. They also highlighted younger ICT users as being more likely to indicate that ICT devices had improved their experience of the time spent on the train.

The analysis of the NRPS data continued, with subsequent waves in 2010 (Lyons, Jain, Susilo, & Atkins, 2013) and 2014 (Lyons, Jain, & Weir, 2016). By the 2010 wave, the analysis incorporated three additional digital activities: checking e-mail, Internet browsing and accessing social networking sites. In addition, the proliferation of new mobile ICT devices had become noticeable and thus smartphones, portable DVD players, MP3/music player, games consoles, eBook reader/tablet computers or netbooks were all included in the survey. What the authors clearly demonstrated in this multi-year effort was, firstly, the emergence and growing popularity of digital activities and, secondly, the rapid and non-monotonic evolution in the types of ICT devices that people use. For example, use of portable music players peaked during the 2010 wave but fell considerably by the 2014, most likely having been made obsolete by the respective functionalities embedded in smartphones.

In another study, Axtell, Hislop, and Whittaker (2008), offered a mixed-methods perspective on travel time use, also in the context of train travel. The study combined an on-board passenger survey with a number of in-depth interviews, leading to an insightful contribution concerning practices of 'mobile technologies' use in mobile spaces' (the authors' own expression captured in their paper title). In their study, the

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[3] Portable Digital Assistant, a predecessor of today's highly capable (in terms of functionalities and computation/communication capabilities) smart mobile devices, including smartphones and tablet computers.

authors suggested a division of digital activities into socially dependent and socially independent. The former include activities that require interacting with other people and make use of ICT to achieve this. The latter, on the other hand, include rather solitary activities that make use of ICT as tools and facilitators. The authors make a particularly interesting observation that, despite the apparent flexibility enabled by mobile ICT, a number of other considerations effectively constrain their potential. Those considerations range from sensitivity and privacy concerns, e.g. due to overhearing or overlooking of information by others, to space constraints and noise level, to lack of reliable connectivity. Importantly, those different considerations will apply differently to socially dependent and independent digital activities, which in turn will determine the practices of mobile technology use, and participation in digital activities, while travelling.

In a study of on-train Internet adoption, Evens, Schuurman, De Marez, & Verleye (2010) looked at arguably the most comprehensive list of digital, and more specifically Internet-using, applications: web browsing, email, news, travel information, access to corporate networks (Virtual Private Networks), instant messaging, e-banking, media streaming, media download, chat rooms, voice over Internet Protocol (VoIP), management of weblogs, e-commerce, online gaming and videoconferencing. The authors indicated, however, that only browsing and e-mail were applications to which the customers attached a significant value. Yet this specific finding must be taken with caution from today's perspective given that the study was reported back in 2010. In line with the intuition, they also showed that early adopters of Internet activities, i.e. people who are enthusiastic about and see the value in such activities, also reported a greater willingness to pay for a wider set of Internet-relying applications, demonstrating a substantial heterogeneity in the perception and value attached to digital activities.

An additional activity type in the form of ‘sharing technology with friends (i.e. showing videos on an iPhone, app’, etc.)’ was identified by Clayton (2012) via a dedicated online research discussion group. This highlights that digital activities might also have a direct social dimension, rather than being a solitary activity involving interactions only via the virtual means. Berry and Hamilton (2010), meanwhile, looked at the use of mobile phones by train travellers in Australia and identified ‘micro-scheduling’, i.e. checking train times, coordinating and updating others about their arrival times, to be a particularly frequent activity. In addition to the activities reported in the previous studies, they also showed a number of respondents engaged in (descending order) updating contacts, clearing inboxes, fiddling with [phone] settings, taking pictures/video, using GPS and checking the stock market, with variations in relative participation observed across age groups.

Pawlak, Circella, Mokhtarian, Polak, and Sivakumar (2016) proposed an analysis of travel time use by means of an extended time allocation framework and employing general time use data, i.e. from a 2010 Canadian survey that was not dedicated only to travel time use. Whilst the authors noted that the survey contained a few digital activities among the secondary activity categories (computer use, talking on the phone, e-mail, chat, social networking, sending/receiving text messages) modelling practicalities (dimensionality of the optimisation problem) meant that they had to collapse these into a single ICT use category. Nevertheless, the authors noted that, within the time use survey, ICT use while travelling was not very prevalent. They attributed the effect, at least partly, to the sample specificity in which travel was predominantly undertaken by car as a driver, probably discouraging active use of ICT as a secondary activity.

Another study, by Bjørner (2016), followed a mixed methods approach to explore travel time use on-board trains in Denmark. The author presented the only evidence so far concerning the extent of multitasking *while* travelling, i.e. conducting multiple activities on-board at the same time. Specifically, the findings pointed out that people could engage in multiple digital activities at the same time, e.g. using mobile phone *and* using laptop/tablet, or digital activities in conjunction with non-digital ones, e.g. eating/drinking or talking with other passengers.

Finally, in the review of travel-based multitasking, Keseru and Macharis (2018, p. 184) grouped ICT-reliant activities into a single 'ICT use' group, defining them as 'using a computer, tablet or smartphone if the purpose of device use is not evident (not for work study)'. Other digital activities would be captured within other activity categories such as non-digital ones – a practice also seen in a number of other studies (see Appendix 1), especially those where the ICT aspect did not constitute the primary research interest.

Beyond the transport and time use oriented literature, a different perspective that is worth explicit emphasis derives from ergonomics-oriented studies, such as those of Kamp, Kilincsoy, and Vink (2011) and Groenesteijn et al. (2014). In those studies, the authors looked at people's postures while conducting activities on-board trains, especially in relation to the growing use of mobile ICT on-board, and ultimately the implications for the comfort of travel. For example, Groenesteijn et al. (2014) concluded that working on a laptop tended to be a lengthy activity but also very constraining in terms of the posture the traveller needs to adopt to make use of the screen and input devices, given the available space. The overarching recommendation of the authors was that, increasingly, participation in digital activity should become a design consideration in order to 'create optimal support for posture to avoid

musculoskeletal risks' (Groenesteijn et al., 2014, p. 1163) as well as ensure comfort of and satisfaction from travel.

Overall, it is possible to observe that the empirical research to date has grown to provide an increasingly comprehensive characterisation of digital activities while travelling. This is a welcome finding that should further encourage efforts towards integrating this knowledge into other branches of transport discipline, especially in relation to policy, planning and transport services provision. A further discussion concerning this broader set of issues as well as suggestions for further research directions are provided in section 6.

5. The role of connectivity in travel-based multitasking

To complement the previous section concerning digital activities, the account below looks at studies that explicitly analysed the role of connectivity and its attributes (speed, reliability, price, ease of use, data allowance and security) in the context of travel-based multitasking. The two-fold intention of the current section is to establish what knowledge exists concerning the role of connectivity and its attributes in enabling digital activities while travelling on the one hand, and to explore what such enablement may imply for indicators of passenger experience on the other.

The first wave of research that appears to touch upon the role of connectivity while travelling (not yet termed travel-based multitasking then) emerged with the arrival of early generation mobile (cellular) telephony, in particular so-called car phones. Consider the statement:

> One way to visualise the combination of these three technologies [automobile, cellular telephony, voice input/output] is through the 'office in the car' concept. In this conceptualization, time spent on the road can become an extension of time in the office. A cellular telephone provides the voice/data communication links.

which resembles statements encountered in the current literature on time use, yet was made back in the 1980s (White, Halas, & Davis, 1986, p. 263). The study already mentioned the expected productivity benefits from being able to transmit data from laptop computers while away from the home office (note that this is even *before* the public commercial use of Internet commenced at scale in late 1980s and early 1990s). Similarly, Mokhtarian highlighted the potentially negative effect of enabling communications while travelling, noting that 'a car phone may discourage a commuter from adopting vehicle trip reduction strategies', thus inhibiting attempts to reduce travel and the consequent congestion (Mokhtarian, 1990, p. 235). Even prior to the above discussions, the late 1970s saw studies focused on how interactions between connectivity-enabled tasks, in particular dialling numbers or lifting the handset, affects driving performance (Kames, 1978). Nonetheless, there were no systematic studies of how those early technologies were actually used, i.e. for what purpose, with what frequency, or how they affected travel experience.

Evens et al. (2010) provided one of the first overviews and discussions of the implementations of mobile Internet on trains. Using a modified approach to the Rogers' diffusion of innovations (Rogers, 2003), the authors sought to establish various segments of travellers with respect to their likelihood and intentions to use on-board Internet in the context of Belgian railways. Using an online survey, the authors observed substantial heterogeneity in terms of motivations and perceived barriers to the adoption of on-board connectivity, ranging from productivity implications, ability to stay informed or consuming media to the preference *not* to be connected or not using the Internet in general. Such drivers would also characterise various adoption segments, e.g. productivity benefits would be emphasised by early adopters whilst noise or the difficulties of using a laptop in the space available on trains was indicated by later

adopters. Furthermore, the authors looked at the role of a range of quality of service indicators, in particular, at costs, reliability, speed, safety, accessibility, continuity, ease of use and payment, anonymity and customer service desks. The authors demonstrated that the most important considerations were costs, reliability, speed and safety (presumably security of the service), and this was largely consistent among the various segments of users (adopters). The study reflected what Brown and O'Hara (2003) noticed in their earlier qualitative inquiry. In particular, they observed a participant who reported on the importance of using a PDA for checking e-mail, but also observed that the slowness of the connection made that difficult, if it was possible at all. They concluded that 'mobile devices were allowing him [the respondent] to form some sort of relationship with his e-mail from the train, [but] the nature of these relationships was not such that the train could be defined as a place where this activity could realistically be done' (Brown & O'Hara, 2003, p. 1571). Through this, they pointed out the importance of connection reliability and, perhaps even more importantly, security of the connectivity and the potential concerns resulting from the public nature of the links. More recently, Jain, Clayton, & Bartle (2017) complemented the set of attributes explored in these studies by presented findings from a comparative study concerning the impact of increasing the free overall data allowance on the propensity to connect to on-train Wi-Fi.

A number of studies have sought to explore the links between the presence of connectivity, typically taken as synonymous with on-board Wi-Fi, and the value of travel time (Banerjee & Kanafani, 2008; Connolly & Caulfield, 2009). In both studies, the modelling results pointed towards positive value attached to on-board connectivity, and thus the potential to reduce the generalised cost of travel and hence the value of travel time savings. More recently, a report commissioned by the UK Department for

Transport (SDG, 2016) explored the value of on-board connectivity in terms the reliability of voice and data connectivity as well as data bandwidth, using a stated preference approach. The study revealed that respondents were willing to pay up to a 29% higher fare to move from no to perfect voice connectivity, and up to 26% more for reliable, high bandwidth data connectivity. The report also demonstrated that if provided with better (higher bandwidth, more reliable) connectivity, the majority of consumers would increase their participation in digital activities, either by consuming more data or by partaking in additional activities. Part of the same report (SDG, 2016) that reviewed some of the existing implementations of Wi-Fi on transport modes, indicated the presence of solid evidence for valuing the connectivity among business passengers and commuters, but very limited evidence concerning leisure travellers. In line with other research, they also emphasised that the presence of connectivity was only one amongst the factors that enable travel time activities, including digital activities, alongside, e.g. seat availability, presence of a table, quietness or crowding level. More recently, Dong et al. (2015) explored the actual ridership implications from the provision of free Wi-Fi on the Amtrak Capital Corridor service in California. They concluded that the service could be associated with a 2.7% increase in ridership, including 8.6%, 6.2% and 1.0% more trips than if Wi-Fi were not available by new, low frequency and high frequency riders, respectively. The implications for ridership could also be drawn based upon contingent valuation study by Bounie et al. (2019) in Paris. The authors reported that provision of optimal connectivity could on average reduce the subjective value of travel time by 12% among public transport users, potentially leading to an increased ridership. The optimal connectivity would thus translate into almost €110M annually for the Paris metro users. Another contribution from that study was an attempt to explicitly distinguish between digital activities that necessarily require

connectivity (‘online’) as opposed to those that can be undertaken without it (‘offline’). Hence they suggested the need to clearly differentiate between problems related to devices as opposed to connectivity in order to understand the value of connectivity.

Regarding implications for the travel time use, the Danish study led by Bjørner (2016) indicated the importance of not only the presence, but also the reliability of the on-board connectivity. In particular, the study provided evidence for the existence of ‘frustration about the predicted vs. actual time use regarding the Internet’ (Bjørner, 2016, p. 691). Furthermore, the study also demonstrated how passengers reported their frustration regarding the prolonged inability of the train operator to provide sufficient connectivity, forming a negative expectation concerning the on-board connectivity (and thus potentially, compromising to some degree the overall travel satisfaction and presumably also the potential for increased ridership).

Pawlak et al. (2017) explored the presence of Wi-Fi as part of their implementation of the joint travel time use and productivity model, using the 2008 Survey of Productive Use of Rail Travel-time (SPURT) from the UK (DfT, 2009). The authors reported a limited impact from the use of Wi-Fi, specifically in observing that when considered jointly with the use of mobile phones, it was associated with a shorter duration of work activity spells. What was also observed, however, was that the use of mobile devices was associated with changes in activity durations and productivity, although there was not enough information concerning the role of connectivity, either on-board or direct from the mobile network, in enabling the use of those devices.

Tang et al. (2018) explored patterns of multitasking on high-speed rail in the Shanghai-Nanjing corridor in China. The authors explored the importance of various possible barriers to work on-board, including the role of Internet stability (or reliability). Their results indicated that an unstable Internet connection was the most important

barrier, identified by 43% of all respondents. The authors pointed out that given the very high prevalence of ICT use among the passengers (96%), investment in an on-board Wi-Fi infrastructure would warrant investigation as a viable strategy to improve the on-board experience. This is especially in light of the present conditions in which on-board Wi-Fi was absent and the users needed to connect to the Internet using their own devices, subjecting them to poorer connectivity caused either by signal attenuation inside the carriage or capacity overload within the local mobile network cell (Ofcom, 2018).

Addressing explicitly the questions of the implications for satisfaction and the significance of connectivity in the context of travelling, Yosritzal, Adji, & Dissanayake (2017) looked at the availability of free on-board or station Wi-Fi in the context of Indonesian rail. Their analysis indicated rather low levels of satisfaction in respect to such amenities, but also indicated that passengers did not consider them equally important to considerations such as ticket price, service reliability or cleanliness. The authors argued this could result from the passengers' ability to connect independently of the on-board Wi-Fi, using mobile network data services, on the one hand. On the other, they also pointed that the *better than expected* performance of such services might pushed them down the hierarchy of considerations require improvement. Interestingly, as part of a focus group conducted alongside this survey, the authors revealed that some passengers expressed that they had difficulties in conducting activities on a moving train whilst others felt uncomfortable using an expensive piece of equipment (smartphone) in crowded conditions when 'other passengers are staring at him/her' (Yosritzal et al., 2017, p. 2714). In fact, the authors indicated that more than 40% of respondents would feel unsafe using a device in a crowded train, which was an interesting consideration neglected in other previous studies.

A slightly different perspective was presented in a recent report from Ofcom (2018), the UK's national communications regulator. The report considered spectrum[4] requirements to accommodate future rail passenger connectivity needs. Specifically, they identified five groups of function-centric online activities that would be expected to drive the connectivity, including watching media, listening to media, communicating, gaming as well as reading/browsing/using (services and applications). Based on an amalgamation of assumptions and limited evidence from the research into time use while travelling, the report set out to provide recommendations concerning bandwidth requirements resulting from the evolution in travellers' digital time use and the consequent needs for connectivity. The consequent assessment was that, in order to meet the unconstrained needs as of late 2018, i.e. to satisfy the entirety of passengers' needs, an *average* of 150 kbit/s per passenger is needed. This was expected to rise to between 600 kbit/s and 2.5 Mbit/s by 2025. These values, however, mask a substantial inter- and intra-passenger variation in the demand driven, for example, by different trip purposes or profiles of participation (types, durations, bandwidth consumption) in various digital activities, which the report largely assumed to average out across passengers. Whilst the report used a simple approach to modelling time use while travelling, it clearly highlighted the value of a detailed understanding of digital activities for the benefit of policy-making and guidance in respect to infrastructure investments.

A recent study by Pudāne, Rataj, et al. (2018) provided an empirical perspective on participation in activities while travelling on-board hypothetical autonomous vehicles, using a focus groups approach. In the study, the authors considered four types of activities based on a combination of whether an activity 'is possible today' or 'will be

[4] Set of (or a range of) radio frequencies allocated to particular telecommunication applications.

new in the future', and the level of priority ('low' and 'high'). Digital activities featured in each category, indicating that their role is expected to persist, if not grow in the world where AVs are present. What also transpired from the findings was that the individuals effectively assumed that digital activities relying on connectivity could be undertaken without obstruction. In other words, the presence of reliable and sufficient (bandwidth, data allowance, cost) connectivity was universally, even if implicitly, assumed, despite the evidence that transport corridors often do not meet this condition.

Looking at the context of air travel rather than surface modes, Schwieterman et al. (2014) observed that the relaxation of the US Federal Aviation Administration's regulations on the use of mobile devices during taxiing, take-off and landing (where use had previously been restricted only to airborne periods using in-flight mode) was not followed by any substantial increase in the use of mobile devices. The authors attributed this rather surprising result to the lack of reliable connectivity, from either the on-board Wi-Fi or mobile network, making it impossible to connect anyway and hence limiting the set of digital activities that they could engage in. Despite the findings for air travel, the authors observed that, for surface modes, the growing prevalence of on-board connectivity, in the form of either on-board Wi-Fi or 3G/4G coverage, has stimulated the use of mobile devices while travelling, in turn affecting the travel experience. Nonetheless, the authors also the emphasised existence of barriers to those trends, such as limited space and legroom, that may hamper the use of more advanced mobile devices and hence engagement in more sophisticated digital activities.

The picture emerging from the account above supports the notion that connectivity has been systematically growing in importance as an enabler of digital activities, especially in light of their increasing reliance on communication and online resources. However, this ability to sustain the increasingly sophisticated online

activities through appropriate levels of service reflected in speed, reliability, price, ease of use, data allowance and security, has been often assumed, either by simply accounting for 'presence' or even completely implicitly. To an extent, this assumption could be seen as increasingly justifiable in an era where access to Internet is becoming classified among basic amenities and rights (Bris, Pawlak, & Polak, 2017). Nonetheless, transport contexts may present particularly challenging circumstances for upholding this assumption which is also discussed in the next section. Hence, it is recommended that any future studies with aspirations to assist suitable infrastructure enhancements appraisal, development of business justification or impact assessment need to explicitly incorporate the various attributes of connectivity in their analyses.

6. Discussion and conclusions

Despite the substantial growth in research efforts concerning travel time use and its experience and productivity implications (Wardman & Lyons, 2016), including progress in conceptual and modelling frameworks (Mokhtarian, 2018; Pawlak, Polak, & Sivakumar, 2015; Pudāne, Molin, et al., 2018), the treatment of digital activities and connectivity within this discourse has rather stalled since the mid-2000s. For example, the types of digital activities explored in most studies are still limited to a relatively small set of basic ones, e.g. e-mail or social media. Confronting this practice with the last decade's continuing evolution in digital services, and the concomitant growth in the sophistication of digital behaviours and the changes in usage patterns driven by the adoption of new services and the obsolescence of old ones (cf. Lyons, 2015) reflects a need for new and focused insights into the role of participation in on-board, connectivity-enabled, digital activities. To that end, a strong recommendation emerging from the review is for future studies to more explicitly consider choosing particular

activity typologies and categories, ideally with a view on comparability with other studies.

Similarly, exploration of the role of connectivity has remained primarily at a level of 'presence of Wi-Fi' with only a handful of studies looking at its attributes, primarily reliability, speed and to a lesser extent cost. Ease of use, data allowance or perceived security have been rarely explored. Knowledge of the attributes characterising the available connectivity, however, is much more valuable to an understanding of the quality of the experience than merely whether or not there is connectivity, especially where that may be only nominal. This also warrants studies that simultaneously look at connectivity attributes as reported by the end users alongside the arguably more objective indicators provided by the infrastructure monitoring tools. Such an approach would provide insights into the roles of prior expectations or experience in determining satisfaction from connectivity while helping to resolve its possible confounding with performance of the end user device itself. Naturally, not all digital activities require connectivity. Furthermore, even among those that do, there will be substantial heterogeneity with respect to requirements for particular connectivity attributes among different profiles of travellers and journeys. Yet without this knowledge, and given the increased coupling between *digital* and *connected*, the understanding of the adoption, popularity and role of ICT and digital activities while travelling will remain incomplete.

Interestingly, both of the above shortcomings appear to be deeply linked to each other. Specifically, consider that provision of on-board connectivity has so far primarily relied on mobile network technologies, primarily 3G and 4G, often in tandem with older technologies, e.g. GPRS, or no coverage at all, especially along remote transport routes with limited ridership. There has been some use of directional radio and satellite connectivity technologies, especially for air and waterborne modes. Nevertheless, this

connectivity landscape implies a typical backhaul[5] with a capacity in the range of tens of megabits per second (Mbps).[6] When shared among tens or, possibly, hundreds of passengers on a train or a plane, this capacity is sufficient to serve only the low-bandwidth, i.e. a few hundred kilobits per second (kbps), applications, e.g. simple web browsing or e-mails, messaging or some social media. This capacity is likely to be insufficient for the more sophisticated and data hungry applications that at present include media streaming, video calls or cloud-based services, and in the future more immersive and interactive services, especially if not provided reliably. The emerging 5G connectivity provision of beyond a gigabit per second connectivity seeks to address some of those issues, although it remains to be seen to what extent this will apply to the context of on-board connectivity. Nonetheless, there is a clear tension between this current landscape of challenges in on-board connectivity provision and the growing expectations of passengers, who are increasingly accustomed to an omnipresent free and good quality connectivity at work, home or in public spaces. This might be also partly the reason for why more sophisticated online activities have not been studied in detail in the previous studies.

The need for insights into the role of digital activities and connectivity in travel-based multitasking ought to be discussed with the view on the implications for valuation of travel time and the implications for relative attractiveness of transport modes. The

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[5] The network link between an on-board network or the device itself and the wider Internet.

[6] The new generation of technologies is expected to achieve capacities beyond an order of magnitude higher than this, including beyond a gigabit per second (Gbps). Nevertheless, those solutions are not yet (2019) in widespread use or offered as a free service to the majority of potential users (passengers).

evidence reported by Wardman et al. (2019) , Bounie et al. (2019) and Molin et al. (2020) provides an increased confidence that facilitation of travel-based multitasking in the form of enablement of digital activities could serve as a policy means supporting modal shifts to promote more sustainable transport alternatives, reduce carbon emissions or balance infrastructure utilisation by encouraging more off-peak travel in conditions more favourable for travel time activities. Nonetheless, credibility of the argument for such interventions will depend on the ability of the domain, currently dominated by rail- and bus-oriented studies, to provide a comparable level of empirical insights in the contexts of long-distance modes (especially air travel), active modes, including shared mobility, micro-mobility, and CAVs. Similarly, a more geographically balanced set of insights should allow assessing more rigorously circumstances under which digitally enhanced travel-based multitasking offers a route to implement transport policy measures.

A perspective complementary to impacts on digital activities on valuation of travel time (savings) concerns their links to indicators of on-board experience, including travel satisfaction and enjoyment, productivity, well-being or fitness. With a handful of exceptions, to date empirical characterisation of such links focused heavily on modelling on-board productivity among business travellers, with remaining indicators being looked at primarily qualitatively. This still limited evidence base concerning such links has arguably stifled the ability of the research community to guide the policy efforts and infrastructure investments aimed at meeting the needs of various types of passengers. Similarly, studies have rarely, if at all, looked at possible risks of travel time digitisation and connectedness. Those could be related, for example, to the expectation of constant availability and the consequent blurring of journey purposes and disruptive fragmentation of activities, to the additional exposure to cybersecurity threats or to the

distribution of benefits from infrastructure improvements along the 'digital divide' dimensions, with those that are digitally skilled benefiting disproportionately more than those that are not.

At the same time, understanding of the role of connectivity even among those passengers that can possibly benefit from it requires an explicit acknowledgment of its (increasingly) necessary, but arguably not sufficient nature in enabling digital activities and improved on-board experience. Digital activities may require suitable 'enabling conditions', relating to possession of suitable ICT devices and other equipment, suitable ambition and attitudes as well as environment that permits undertaking such activities, including space, facilities (table, socket), seat ergonomics and intimacy. Whilst those conditions have been reported in the literature (e.g. Jain & Lyons, 2008; Keseru & Macharis, 2018), the existing efforts have rarely explored them as suitable non-linear effects, thresholds or non-compensatory decision mechanisms in modelling the links between connectivity, digital activities and journey conditions. Yet such advancement in understanding is essential for a more complete understanding of conditions under which benefits from digitisation of travel time can be realised.

Thus, while transport operators direct their attention to improving the connectivity provision, reflected ultimately in its attributes, transport users continue to become more sophisticated in their online behaviour. To enable a better alignment between the two, the research community must develop a robust understanding of how attributes of the on-board connectivity relate to the propensity to participate in digital activities, and how this, in turn, relates to on-board experience indicators and ultimately drivers of travel behaviour, including choices of mode or time of travel. Only then will it become possible to start confidently closing the loop between modal attractiveness and ridership (and hence revenue) or broader impacts (congestion, environment,

productivity, well-being) on the one hand, and digital behaviour, and investment in connectivity for transport modes on the other.

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No potential conflict of interest is reported by the author.

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Appendix 1. List of studies identified and their treatment of digital activities and connectivity while travelling

Table 1. List of studies identified and their treatment of digital activities and connectivity while travelling

	Data context			Digital activities			Explicit connectivity: presence and attributes						
Study	**Country**	**Year**	**Mode(s)**	**Hardware-centric**	**Function-centric**	**Merged with non-digital**	**Presence**	**Speed**	**Reliability**	**Price**	**Ease of use**	**Data allowance**	**Security**
Axtell et al. (2008)	UK	2006	rail		●	●	●		●	●			
Banerjee and Kanafani (2008)	USA	2005	rail				●			●			
Banister, et al. (2016)	n/a	n/a	n/a	●	●								
Berry and Hamilton (2010)	Australia	2007	rail		●								
Bjørner (2016)	Denmark	2012	rail	●	●		●		●	●			
Bounie, et al. (2019)	France	2015	public transport		●		●		●				

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Brown and O'Hara (2003)	UK	n/a	car, rail	●	●		●	●	●				●
Chin, et al. (2019)	China	n/a	rail	●			●		●				
Clayton (2012)	UK	2009-11	bus (urban)	●	●								
Clayton, et al. (2017)	UK	2009-11	bus (urban)	●	●								
Connolly and Caulfield (2009)	Ireland	2008	rail	●	●					●			
DfT (2009)	UK	2008	rail	●	●	●	●		●				
DfT (2012)	UK	2012	rail		●								
DfT (2015)	UK	2015	rail		●								
Dong, et al. (2015)	USA	2012	rail				●						

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Verschuren and Ettema (2007)	Netherlands	2005	car, public transport	●									
Ettema et al. (2012)	Sweden	2010	public transport	●	●								
Evens et al. (2010)	Belgium	n/a	rail		●		●	●	●	●	●		●
Fischer and Schwieterman (2011)	USA	2010-11	bus (intercity)		●		●						
Flamm (2005)	Switzerland	n/a	bicycle, car, bus (urban), rail, tram, walk	●	●								
Frei et al. (2015)	USA	2010	metro	●	●								

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Gamberini et al. (2013)	UK	2010	metro	●									
Gripsrud and Hjorthol (2012)	Norway	2008	rail		●		●						
Groenesteijn et al. (2014)	Belgium, France, Netherlands, UK	n/a	rail	●	●								
Guo et al. (2015)	Canada	2012	bus (urban)	●									
Gustafson (2012)	Sweden	n/a	all	●	●		●						●
Hislop and Axtell (2009)	UK	n/a	all	●	●		●						
Hislop and Axtell (2015)	UK	n/a	car, rail, air	●	●								
Hislop (2013)	UK	2009	car	●			●						

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Holley et al. (2008)	UK	2004	rail	●	●								
Jain and Lyons (2008)	UK	n/a	all	●	●		●						
Jain et al. (2017)	UK	2015-17	rail		●		●		●			●	
Kamp et al. (2011)	Germany, Netherlands	n/a	rail	●									
Keseru et al. (2015)	Belgium	2013-2014	bicycle, car, motorbike, public transport, walk		●								
Keseru et al. (2020)	Belgium	2016	bus (urban), metro, tram										

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Khan and Sundstrom (2007)	Sweden	n/a	rail	●	●								
Kouwenhoven & de Jong (2018)	Netherlands	2011	bus (urban), car, metro, rail, tram	●									
Laurier (2002)	UK	n/a	car	●	●		●						
Lee, Chul Kim, Kook Wu, & Oh, (2019)	South Korea	n/a	bus (urban), metro		●		●	●	●			●	
Lehmuskoski (2007)	Finland	2007	bus (urban)				●						
Line et al. (2011)	UK	2008-09	all	●	●		●						

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Lugano and Cornet (2018)	Belgium, Croatia, Finland, Italy, Portugal, Romania, Slovakia, Spain, Switzerland	2018-2020	all	●	●								
Lyons et al. (2007)	UK	2004	rail	●	●								
Lyons et al. (2013)	UK	2010	rail	●	●								
Lyons et al. (2016)	UK	2014	rail	●	●								
Malokin et al. (2015)	USA	2011-2012	bicycle, car, public transport, ride sharing, rail	●	●								

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Molin et al. (2020)	Netherlands	n/a	rail		●								
Neufeld and Mokhtarian (2012)	USA	2011-2012	public transport, carpooling	●	●		●			●			
Ofcom (2018)	UK	2018	rail		●			●					
Ohmori and Harata (2008)	Japan	2004	rail	●	●		●			●			
Pawlak et al. (2016)	Canada	2010	all		●	●							
Pawlak et al. (2017)	UK	2008	rail			●	●						
Pawlak and Polak (2010)	UK	2004	rail	●	●								
Pawlak et al. (2015a)	UK	2014-15	all		●		●						

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Pudāne et al. (2018b)	Netherlands	2017	car (autonomous)		●	●							
Rasouli and Timmermans (2014)	Netherlands	n/a	car, bus (urban), rail, tram		●		●						
Rhee et al. (2013)	South Korea	2012	car, public transport		●								
Russell et al. (2011)	New Zealand	2008	bus (urban), rail	●									
Russell (2012)	New Zealand	2009-2010	bus (urban), rail	●	●	●							
Schwieterman et al. (2014)	USA	2009-2014	bus (intercity), rail, air		●		●						
SDG (2016)	UK	2015-16	rail		●		●	●	●	●			

Table 1. List of studies identified and their treatment of digital activities and connectivity while travelling

Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Singleton (2018)	USA	2016	bicycle, bus (urban), car, public transport, walk		●								
Tang et al. (2018)	China	2016	rail		●		●		●				
Tapley (2008)	UK	2007	rail				●						
Thomas (2009)	New Zealand	n/a	bus (urban), rail	●									
Timmermans and Van der Waerden (2008)	USA	2007	metro	●	●								
Van der Waerden et al. (2009)	Netherlands	2007	rail	●	●								

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Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Van Hagen et al. (2017)	Netherlands	2013-2015	rail		●	●							
Varghese and Jana (2018)	India	2016	bicycle, bus (urban), car, rail, walk		●								
Varghese and Jana (2019)	India	2016	bicycle, bus (urban), car, rail, walk		●								
Vilhelmson et al. (2011)	Sweden	2008-2009	bus (urban), rail	●	●		●						
Wang and Loo (2018)	China	2016	rail		●		●		●				
Wardman et al. (2019)	UK	2014	Rail	●	●								
Wester (2011)	Netherlands	2011	bus (urban), car metro, rail	●	●		●						

Table 1. List of studies identified and their treatment of digital activities and connectivity while travelling

Study	Data context			Digital activities			Explicit connectivity: presence and attributes						
	Country	Year	Mode(s)	Hardware-centric	Function-centric	Merged with non-digital	Presence	Speed	Reliability	Price	Ease of use	Data allowance	Security
Yosritzal et al. (2017)	Indonesia	2014	rail		●		●						
Yosritzal (2014)	UK	2011	rail		●		●						
Zhang & Timmermans (2010)	Japan	2008	bus (urban), rail	●	●								

Appendix 2. List of studies identified and their treatment of digital activities and connectivity while travelling

Table 2. Summary of the reviewed studies in their treatment of digital activities and connectivity while travelling by transport mode and geographical context

	Digital activities typology convention				Explicit connectivity						
	Hardware-centric	**Function-centric**	**Mixed**	**Merged with non-digital**	**Presence**	**Speed**	**Reliability**	**Price**	**Ease of use**	**Data allowance**	**Security**
Transport Modes											
Air		1	1		1						
Bicycle		4	2								
Bus											
urban	4	5	8	1	5	1	1			1	
intercity		2			2						
Metro and tram	2	2	5		3	1	1			1	
Private motorised											
car and motorbike	3	6	6		7	1	1	1			1
carpooling and ride sharing			2								
car (autonomous)		1		1							
Public transport (not further specified)	1	4	3		2		1	1			
Rail	4	19	20	2	24	4	10	7	1	1	2
Walk		4	1								
Not further specified ('all')		2	5	1	5						1

Table 2. Summary of the reviewed studies in their treatment of digital activities and connectivity while travelling by transport mode and geographical context

	Digital activities typology convention				Explicit connectivity						
	Hardware-centric	**Function-centric**	**Mixed**	**Merged with non-digital**	**Presence**	**Speed**	**Reliability**	**Price**	**Ease of use**	**Data allowance**	**Security**
Geography											
Asia	*1*	*7*	*2*	*0*	*6*	*1*	*4*	*1*	*0*	*1*	*0*
China	1	2			3		3				
India		2									
Indonesia		1			1						
Japan			2		1			1			
South Korea		2			1	1	1			1	
Australia & Oceania	*2*	*1*	*1*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Australia		1									
New Zealand	2		1	1							
Europe	*6*	*14*	*39*	*4*	*23*	*4*	*8*	*5*	*1*	*1*	*2*
Belgium		2	3		1	1	1	1	1		1
Croatia			1								
Denmark			1		1		1	1			
France		1	1		1		1				
Finland			1		1						
Germany	1										
Ireland			1					1			
Italy			1								

Table 2. Summary of the reviewed studies in their treatment of digital activities and connectivity while travelling by transport mode and geographical context

	Digital activities typology convention				Explicit connectivity						
	Hardware-centric	**Function-centric**	**Mixed**	**Merged with non-digital**	**Presence**	**Speed**	**Reliability**	**Price**	**Ease of use**	**Data allowance**	**Security**
Netherlands	3	4	3	2	2						
Norway		1			1						
Portugal			1								
Romania			1								
Slovakia			1								
Sweden			3		1						
Spain			1								
Switzerland			3								
UK	2	6	17	2	15	3	5	2		1	1
North America	*1*	*3*	*4*	*1*	*5*	*0*	*0*	*2*	*0*	*0*	*0*
Canada	1	1		1							
USA		2	4		5			2			