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Data and digital systems for UK transport: change and its implications

Future of Mobility: Evidence Review

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Data and digital systems for UK transport: change and its implications

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Executive summary

Rapid evolution in digital systems, technology and the availability of data resources are having considerable impacts on the UK's transport network. To fully capitalise on the potential benefits of these developments, additional research and innovation are needed in terms of digital infrastructure, development of digital skills, and availability and understanding of underlying data resources. This report describes the current state of the UK's digital infrastructure for the transport network, along with emerging trends and developments. In this report, these developments are contextualised with particular reference to emerging transport systems and networks, particularly related to connected and autonomous vehicles (CAVs) and mobility as a service (MaaS), both of which represent key considerations in the digital realm.

The evidence indicates that, while the UK's digital coverage is generally suitable for current purposes, gaps remain in terms of geographic coverage, especially in the continued presence of the 'digital divide', particularly in reference to rural and urban dichotomies. In addition, the demands of emerging transport technologies in terms of data usage and coverage will likely be significantly higher than those currently experienced, highlighting the need to better future-proof the UK's digital network. Complementary digital skills and access to data are also recognised as critical players in efforts to fully engage the transport network in digital systems, particularly insofar as they support research, development and the implementation of innovative transport systems. Further considerations related to interdisciplinary training for practical applications in the transport realm will be required to develop a fully comprehensive transport network.

Contents

1. Introduction

The evolution of digital technology has had myriad effects on the provision of transport services, in both the passenger and freight sectors. In a 2016 report, Transport Systems Catapult (TSC) stated:

> 'Intelligent Mobility is the future of transport. It is about harnessing innovation and emerging technologies to create more integrated, efficient and sustainable transport systems. It marks an exciting meeting point between traditional transport and the new products and services that are emerging as we start to exploit vast amounts of multi-layered data. As such it offers us a remarkable opportunity to make much more efficient use of networks and to revolutionise transport, all driven by the needs of the end user.'

TSC, 2016a p. 4.

While the opportunities emerging in the area of 'intelligent mobility' are considerable, the requirements they place on the underpinning technology and data are also substantial, and understanding the relationships between technology, data and transport will be critical for fully capitalising on these opportunities. This report explores the changing nature of data and digital systems in the UK and addresses how this will impact on the provision of transport services. Beginning with an overview of recent changes to the UK's digital systems for transport, the report examines the effects on transport users, focusing on engagement and emerging needs. It then looks at how technological evolution is driving innovation in the transport sector. Finally, the issue of data is explored, with particular attention paid to the way in which data is enabling the development of new models of transport provision.

2. Context

For the purposes of illustrating how changes in the digital realm will affect the provision and evolution of transport systems, this report refers to the concept of mobility as a service (MaaS), and to connected and autonomous vehicles (CAVs), both of which are subject to increased interest from transport researchers and practitioners. MaaS, a proposed system that combines different modes of transport and complementary services that are purchased as a package tailored to the individual user's needs, demonstrates a range of technological and digital innovations. Such service models are posited to draw together innovations in real-time information, mobile ticketing, journey planning and modal integration, generally offered through smartphone apps or online (Hietanen, 2014; Sochor et al., 2015; Kamargianni et al., 2016). To be effective, however, MaaS requires a high level of user connectivity and understanding as well as integrated back-end systems, making it a useful case study for examining digital systems.

Connected[1] and autonomous vehicles, also known as self-driving vehicles, have undergone an increasing amount of research and innovation in recent years, with testing and development

[1] Connected vehicles, according to Lu et al., 'refer to the wireless connectivity-enabled vehicles that can communicate with their internal and external environments, i.e., supporting the interactions of vehicle-to-sensor on-board (V2S), vehicle-to-vehicle (V2V), vehicle-to-road infrastructure (V2R), and vehicle-to-Internet (V2I)... These

taking place in the private sector (Fagnant and Kockelman, 2015), academia (Chong et al., 2013) and the public sector (TSC, 2016b). While the focus has been on the vehicles themselves, transferring data to and from CAVs as they travel will be key to ensuring that CAVs reach their full potential in the wider transport system, with Anderson et al. (2014) noting requirements for telematics to constantly update the 'state of the world', to support vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, and to provide critical software updates. These activities require widespread, reliable and consistent digital coverage if CAVs are to be implemented over a broad network.

3. Changes in the UK's digital system

In March 2017, the UK's Department for Digital, Culture, Media and Sport (DCMS, 2017a) published its strategy, which identified seven core priorities for digital technology in the UK:

1. Connectivity: building world-class digital infrastructure for the UK
2. Digital skills and inclusion: giving everyone access to the digital skills they need
3. The digital sectors: making the UK the best place to start and grow a digital business
4. The wider economy: helping every British business become a digital business
5. A safe and secure cyberspace: making the UK the safest place in the world to live and work online
6. Digital government: maintaining the UK government as a world leader in serving its citizens online
7. Data: unlocking the power of data in the UK economy and improving public confidence in its use.

It is notable that these priorities incorporate not only physical digital infrastructure, but also the skills, training and data that will populate the digital sector. How well these aims are being addressed, however, remains in question – the DfT-commissioned Scoping Study into Deriving Transport Benefits from Big Data and the Internet of Things in Smart Cities (Department for Transport, 2017), for example, suggests that the exploitation of big data and digital resources in the transport sector presents opportunities in terms of maximising efficiencies, improving asset management and enhancing the customer experience. However, the level of maturity in the exploitation of benefits is much lower in transport than in other sectors such as healthcare, finance and retail.

This section discusses the overarching need for data and digital systems in the UK, focusing on digital infrastructure, before addressing in more detail the ways in which these needs impact on the transport sector.

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interactions, establishing a multiple levels of data pipeline to in-vehicle information systems, enhance the situational awareness of vehicles and provide motorist/passengers with an information-rich travel environment (2014, p. 289).'

Digital service provision

Quality and reach

Ofcom's report *Comparing Service Quality* 2016 (Ofcom, 2017a) found that while most customers are satisfied with the quality of their broadband and phone services, over one in 20 had reasons for complaint about their mobile services, while one in 10 had reasons for complaint about their broadband services. Slow or patchy performance were the most cited reasons for complaint. There is also clear evidence of a digital divide in terms of access to, and performance of, digital infrastructure in the UK, with Philip et al. (2017) finding that the average percentage of superfast broadband availability differed substantially across England (76.3%), Scotland (43.7%), and Wales (40.1%) in 2013, with even more significant differences seen between urban and rural areas. Such figures are, however, improving, with Ofcom claiming that, by 2014, virtually all premises in the UK had access to some form of broadband (Ofcom, 2015). These figures may, however, fail to account for the overall *geographic* coverage of broadband, and figures for access to superfast and ultrafast broadband still demonstrate a lack of overall coverage (Ofcom 2015, 2016, 2017c; see Table 1). Take-up of these services has also been somewhat low.

Table 1: Broadband availability across the UK

Fixed broadband	**2014**	**2015**	**2016**
Broadband, all speeds			
Coverage, premises	~100%*	~100%*	~100%*
Take-up, premises	73%	78%	78%
Average download sync speed	23 Mbit/s	28 Mbit/s	37 Mbit/s
Superfast broadband (download speed between 30Mbit/s and 300 Mbit/s)			
Coverage, premises	75%	83%	89%
Take-up, premises	21%	27%	31%
Average download sync speed	54 Mbit/s	63 Mbit/s	74 Mbit/s
Ultrafast broadband (download speed greater than 300 Mbit/s)			
Coverage, premises	N/A	2%	2%
Take-up, premises	N/A	0.00%	0.09%

**reported figures have been rounded and include a proportion on small businesses without access*

Source: Ofcom, 2015, 2016, 2017c

Limited rates of take-up may belie actual demand, as indicated in the report of the House of Commons Select Committee on Culture, Media and Sport (CMS):

> ‘Over the last few years a key concern has been a growing digital divide between those who have good access to communication services and those who do not. The effect on those in rural areas has been much discussed, but it is startling that access to decent broadband remains a major problem for many small businesses especially in business parks, for homes on new estates across the country and also in city centres, including the heart of London.’

House of Commons Select Committee on CMS, 2017 p. 7

This is corroborated by Ofcom’s report, which states that:

> ‘Small businesses increasingly rely on broadband, but a disproportionate number cannot access even a basic service. We estimate that almost 230,000 small businesses (7%) cannot receive decent broadband… We see a similar pattern for superfast broadband, where around 500,000 small businesses (16%) do not have access, compared to 9% of premises as a whole.’

Ofcom, 2017c p. 2

A key message is that while availability may exist, patterns of the quality of access may be more variable. Such divides are important for residents and businesses, but may also impact on public services. With an increasing focus on ‘smart cities’,[2] securing adequate universal connectivity (likely utilising a mixture of telecoms services including wi-fi, 3G, 4G, and other emerging technologies) will be critical for ensuring reliable and comprehensive services.

Capacity and demand

Connectivity alone, however, is insufficient: there are also rising demands on digital services to consider, as daily use of bandwidth and data increases. A recent study from Cambridge Judge Business School reported concerns as to whether ‘technological capabilities are keeping pace with dramatic increases in demand, as optical fibre has a finite information flow’ (Oughton et al., 2017). Other trends, including a 45% increase in the take-up of mobile internet services between 2010 and 2016 indicate that the appetite and need for internet access remain strong.

However, the authors also report that in spite of coverage of 3G and 4G being over 70%, ‘average data consumption per user is increasing rapidly which is now over 1 GB per month (Oughton et al., 2017). As digital networks are increasingly called on to address the needs of residential and business users in addition to public services, future-proofing for capacity requirements will only increase in importance.

Meeting such requirements, in turn, has been shown to have beneficial impacts that stretch beyond simple convenience. According to a 2011 report, the internet contributed 5.4% of the UK’s 2009 GDP, and 23% of overall growth from 2004 to 2009 (Pélissié du Rausas et al., 2011). Stocker and Whalley (2017) report that internet access has been found to have beneficial impacts on employment levels, environmental management and resilience to climate change. Such benefits are highlighted in the 2015 report *Two-speed Britain: Rural internet use*, which demonstrated the wide variety of activities for which the internet is used, ranging from social engagement and entertainment, daily activities such as paying bills or purchasing goods, to work-related tasks (Farrington et al., 2015). Figures from the Ofcom Technology Tracker report (Ofcom, 2017b) support these results, with the most common use of the internet being for information and communication purposes, followed by purchasing or financial activities, and social and entertainment purposes (Table 2). Additional activities reported related to communications, accessing news and downloading information for work or educational purposes (Table 3).

[2] ‘Smart cities’ are defined by the British Standards Institute (BSI) as ‘the effective integration of physical, digital and human systems in the built environment to deliver sustainable, prosperous and inclusive future for its citizens’ (BSI, 2014).

Table 2: Use of the internet by activity

For those who use the internet at home or elsewhere, which, if any, of these activities have you used the internet for in the LAST WEEK?

		GENDER		AGE GROUP				NATION			
	Total	**M**	**F**	**16-24**	**25-34**	**35-54**	**55+**	**ENG**	**SCOT**	**WALES**	**NI**
Total Sample	2114	1028	1086	327	386	772	629	1782	175	101	56
		49%	*51%*	*15%*	*18%*	*37%*	*30%*	*84%*	*8%*	*5%*	*3%*
INFORMATION	1798	895	903	284	349	673	491	1524	144	86	44
	85%	*87%*	*83%*	*87%*	*90%*	*87%*	*78%*	*86%*	*82%*	*85%*	*79%*
COMMUNICATION	1741	855	886	296	342	656	447	1484	142	79	36
	82%	*83%*	*82%*	*91%*	*89%*	*85%*	*71%*	*83%*	*81%*	*78%*	*64%*
PURCHASING/ FINANCES	1398	670	727	217	303	559	319	1189	109	75	24
	66%	*65%*	*67%*	*67%*	*78%*	*72%*	*51%*	*67%*	*62%*	*75%*	*42%*
SOCIAL	1099	525	573	238	252	412	197	941	81	55	22
	52%	*51%*	*53%*	*73%*	*65%*	*53%*	*31%*	*53%*	*46%*	*54%*	*39%*
ENTERTAINMENT	1084	565	518	244	253	410	176	943	76	45	19
	51%	*55%*	*48%*	*75%*	*65%*	*53%*	*28%*	*53%*	*43%*	*45%*	*34%*
REMOTE ACCESS	424	225	199	83	104	175	63	372	31	18	4
	20%	*22%*	*18%*	*26%*	*27%*	*23%*	*10%*	*21%*	*18%*	*17%*	*6%*

Source: OFCOM TECHNOLOGY TRACKER - H2 2017. 1st July to 31st August 2017 (Table 58).

All data have been weighted to ensure they are representative of the UK adult population.

Source: Ofcom, 2017b

Table 3: Use of the internet by secondary activity

For those who use the internet at home or elsewhere, which, if any, of these activities have you used the internet for in the LAST WEEK?

		GENDER		AGE GROUP				NATION			
	Total	**M**	**F**	**16-24**	**25-34**	**35-54**	**55+**	**ENG**	**SCOT**	**WALES**	**NI**
Total	2114	1028	1086	327	386	772	629	1782	175	101	56
		49%	51%	15%	18%	37%	30%	84%	8%	5%	3%
Communicating via instant messaging	981	464	517	226	232	366	159	844	68	49	20
	46%	45%	48%	69%	60%	47%	25%	47%	39%	48%	35%
Accessing news	891	471	420	132	199	351	209	768	67	43	14
	42%	46%	39%	40%	51%	46%	33%	43%	38%	42%	24%
Finding/ downloading information for work/ business/ school/ college/ university/ homework	757	375	382	149	181	309	118	661	51	38	7
	36%	37%	35%	46%	47%	40%	19%	37%	29%	38%	13%
Watching short video clips	725	384	342	171	189	271	95	641	41	32	12
	34%	37%	31%	52%	49%	35%	15%	36%	23%	31%	22%

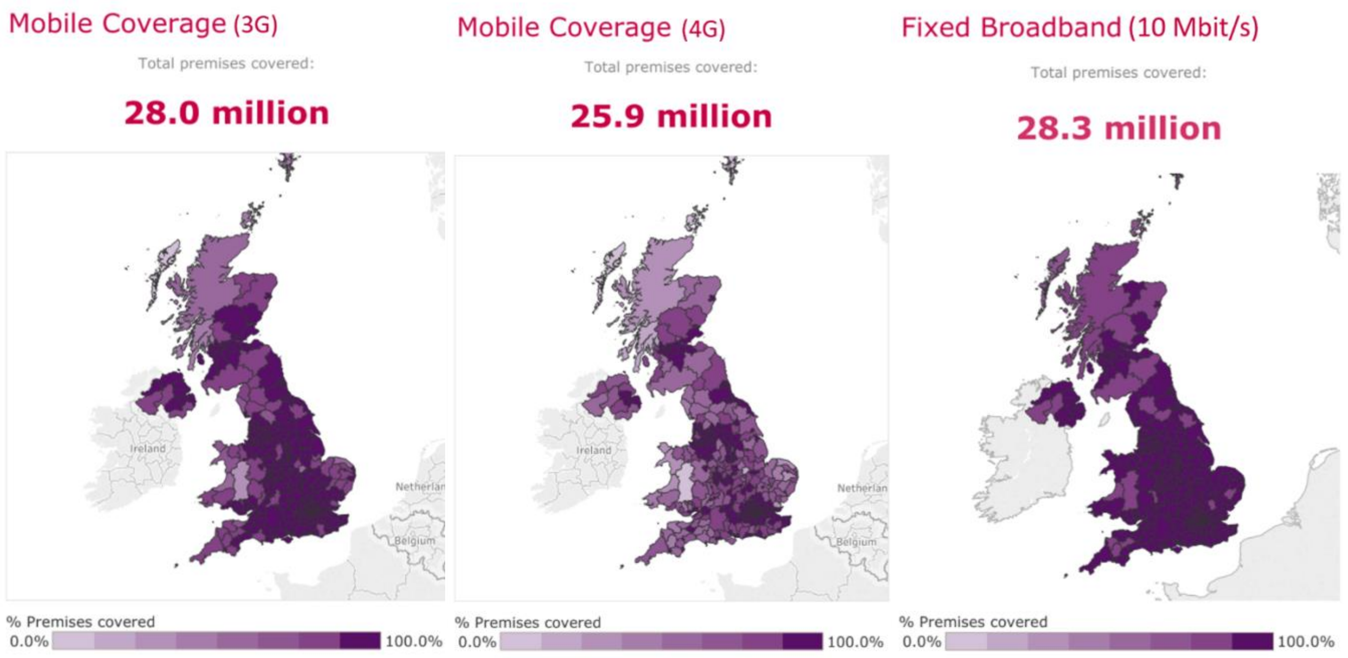
Source: OFCOM TECHNOLOGY TRACKER - H2 2017. 1st July to 31st August 2017. Table 58.

All data have been weighted to ensure they are representative of the UK adult population.

Impacts on the transport sector and research needs

Balancing the spectrum of needs for high-quality internet services across the public and private spheres will be challenging, as capacity requirements increase along with technological enhancements in the transport sector. As noted in the discussions of MaaS and AVs above, a key component in ensuring that the transport sector is able to make full use of emerging technologies and systems is comprehensive and reliable digital connectivity. Given the increasing reliance of transport information and service provision on digital connectivity (Kos-Łabędowicz and Urbanek, 2017), unreliable or inconsistent service as a result of digital divides or digital ‘dark areas’ may have negative consequences for comprehensive transport service provision. Figure 1, generated from Ofcom data (2017c), shows spatial trends in the household coverage of mobile services and low-speed broadband services. When compared with data from Farrington et al. (2015) (based on 2013 data), the trend of lower quality services in rural and remote areas has remained generally consistent over time. The literature indicates that this is largely a result of economic considerations, with Salemink et al. (2017) reporting that ‘Compared to urban areas, the profit opportunity in rural areas is lower because of the high costs of covering greater distances. Companies are only willing to deploy a network if households and businesses pay a higher price to make up for these higher deployments costs’ (p. 367).

Figure 1: Household coverage of 3G and 4G mobile and 10Mbit/s broadband connections in the UK (2017 data)



Source: Ofcom, 2017c

Similarly, Table 4 shows there are still significant areas of roadway that are not covered by a consistent mobile data service. Although these areas are declining in number, they are often remote or isolated from other services, compounding the detrimental impact of a lack of service (Ofcom, 2017b). The spatiality of transport in relation to the need for mobility requires that a consistent service be available while travelling, in order to provide and obtain up-to-date information, respond to disruptions, and, potentially, receive critical software updates. Further examination of the nexus between large-area digital service provision and the underlying transport network is critical if the UK is to benefit fully from emerging transport technologies and innovative service provision models.

Table 4: Mobile network coverage across the UK

Mobile services	**2015**	**2016***	**2017**
4G services			
Premises (indoor) covered by all operators	29%	40%	58%
Geographic area not covered by any operator	52%	37%	22%
A and B roads not covered by any operator	47%	35%	16%
Voice services (2G, 3G and 4G)			
Premises (indoor) covered by all operators	85%	89%	90%
Geographic area not covered by any operator	13%	11%	9%
A and B roads not covered by any operator	10%	7%	5%
Data services (3G and 4G)			
Premises (indoor) covered by all operators	77%	80%	85%
Geographic area not covered by any operator	21%	16%	12%
A and B roads not covered by any operator	15%	11%	7%

Source: Ofcom, 2016, 2017b

** Where figures varied from the 2016 to 2017 reports, 2017 figures were used.*

Given the increasing reliance of both passenger and freight transport on digital systems, it seems likely that the need to provide more comprehensive and reliable coverage across all travel networks will only increase. Growth trends in online shopping, increasing use of real-time and on-demand apps for travel and transport information, and the convenience that these services offer all indicate that the provision of extensive coverage will increasingly become an expected part of travel across the UK. Such expectations may, however, heighten risks if the market opportunities or practices providers implement fail to acknowledge limitations of the available digital system. While locating freight warehouses in largely rural areas, for example, may make sense in terms of property values and availability of space, limitations in digital connectivity in such areas may constrain the efficiencies gained through delays in communications, for example, or inability to provide reliable real-time routing decisions.

Future considerations

Costs

While the current focus has been on the provision of reliable and fast broadband, and good geographic coverage for 2G, 3G and 4G mobile services, the need to future-proof has seen increasing interest in 5G coverage. In March 2017, the UK government announced its ambitions to be a world leader in 5G technology, with potential benefits cited as including connected/driverless lorries and vans, smart cities and improvements in the quality of urban life through enhanced traffic management, streetlight control and waste management (DCMS, 2017b). For these benefits to be achieved, however, the geographic coverage of services must be aligned with roadway locations. This, however, is not a simple or inexpensive task, as indicated by LS Telcom in a 2016 report produced for the National Infrastructure Commission:

> ‘We conducted a network dimensioning analysis to understand the infrastructure capabilities needed to deliver future enhanced mobile broadband connectivity to road users. The following site numbers and costs have been estimated for both a dedicated roadside network and expansion of the MNOs [Mobile Network Operators] network adjacent to the roadside.
>
> 1) To deliver the very high mobile broadband speeds that would be expected in 5G the number of sites needed along the motorway part of the SRN [strategic road network] in Britain ranged from approximately 7300 to 18270.
>
> 2) Connecting these sites to the existing roadside fibre and fixed infrastructure along the motorway part of the SRN in Britain would cost between £183 million and £457 million.
>
> 3) The number of required sites increases to approximately 24300–60650 to cover all the SRN in Britain. However, new fibre would be needed in all non-motorway sections of the SRN to replace the existing copper cable.
>
> 4) Connecting these sites to the existing fibre and fixed infrastructure and newly laid fibre where it does not already exist would cost between £1.75 bn and £5.1 bn.
>
> 5) An alternative would be for MNOs to increase their sites along the roadside (assuming it is on the land adjacent to the roads). Our cost estimates based on MNO deployments ranges from £743– £1.1bn for all motorways in GB. This increases to £4.1bn–£7.8bn for all the SRN in Britain.’
>
> LS Telcom, 2016 p. 9

Such costs demonstrate the need to more fully integrate considerations of future-proofing for digital needs into budgetary and planning decisions.

Data requirements

Such considerations related to emerging needs for reliable, fast, low latency and comprehensive data coverage become increasingly critical if we consider the potential for more widespread roll-out of CAVs. Brian Krzanich, CEO of Intel, has suggested that:

> ‘In an autonomous car, we have to factor in cameras, radar, sonar, GPS and LIDAR – components as essential to this new way of driving as pistons, rings and engine blocks. Cameras will generate 20–60 MB/s, radar upwards of 10 kB/s, sonar 10–100 kB/s, GPS will run at 50 kB/s, and LIDAR will range between 10–70 MB/s. Run those numbers, and each autonomous vehicle will be generating approximately 4,000 GB – or 4 terabytes – of data a day.’

Krzanich, 2016

With such massive data requirements on the horizon, requirements for secure, reliable and interconnected data centres will only grow (Giarratana, 2017). Required vehicle-to-infrastructure (V2I) communication systems for cooperative AV systems will include vehicle status data, convoy management, manoeuvre negotiation, intersection management and cooperative sensing (Hobert et al., 2015). Performance requirements to allow these systems to be reliable and secure will include a high message rate, data-load control, low end-to-end latency and highly reliable packet delivery (Hobert et al., 2015). Ensuring that these requirements can be met over both space and time in the vehicle network will require an integrated, comprehensive approach to the roll-out of high-capacity data networks over the transport system. Work is currently ongoing within the DfT to explore different technology options to meet these needs.

The temporal aspect is a critical component here, as some data generated for optimum performance of autonomous and/or connected vehicles will require immediate transmission, while other data may be collected and transmitted at the start or end of a journey, or while undergoing servicing and maintenance. Data associated with incidents or issues on the roadway (such as traffic crashes, potholes or objects in the roadway) will require reliable, timely V2I communication. Data associated with the movement of the vehicle through space and in coordination with other vehicles on the roadway will need near-instantaneous vehicle-to-vehicle (V2V) (and potentially V2I) transmission in order to allow decisions to be made in real time and cooperatively. Given the density of vehicles on particular sections of roadway, and during particular times, the resulting information load on the system may be quite high (Seo et al., 2016). Intel has estimated that approximately 1 GB of data will need to be processed (though not necessarily transmitted) each second in the car’s real-time operating system in order for the vehicle to react in less than a second (Intel, 2014).

Seif and Hu (2016) have identified bottlenecks that might inhibit the achievement of these data requirements for AVs:

- data collection: One hour of drive time corresponds to one terabyte of data
- data processing: Interpreting one terabyte of collected data using high computing power requires two days to produce usable navigation data
- data transmission: Although today’s available 4G allows data transmission at 100 Mbit/s, 2.2 Gbit/s are required. However, 5G enables 5 Gbit/s and will be market-ready in 2020+

- latency time: For real-time execution, latency must be lower than 10 milliseconds, which requires high-performance computing onboard the vehicle

Effectively overcoming these barriers to enable reliable, timely transmission and processing of data represents one of the core challenges facing the emerging transport network.

Vehicle development

There are also strenuous demands on CAVs themselves. Hyundai, which recently set a record for autonomous highway driving with its Nexo SUV, believes that the capacities of AVs require further research and innovation, particularly in terms of the speed of data-processing (Galeon, 2018). Katrakazas et al. (2015) highlight the necessity for timely and accurate planning within an AV's navigation system, noting its demand on computational memory, and its need to run simultaneously with routine operations such as obstacle tracking and planning, especially in an urban mixed-traffic scenario. To meet the functional requirements for planning to take place, the authors assert that more research is needed on such computationally demanding operations as obstacle handling, vehicle dynamics, risk indicators, and sensing and perception.

4. User engagement

To fully engage with digital transport systems, users require:

1. the enabling infrastructure, such as reliable connectivity

2. digital devices, such as personal computers or smartphones

3. the skills required to use these

The development of digital skills requires access to reliable digital technologies in order to facilitate on-going training and development. Van Deursen et al. (2016) have extensively studied digital skills and state the case for regarding the skills required to use the internet as being distinct and more demanding than IT skills more generally, in that users must learn search and communication skills. This finding is pertinent in two ways: first, many transport technologies (including journey planning, mobile ticketing and information seeking) require active use of internet-enabled technologies; indeed, apps and internet-enabled technologies increasingly provide incentives to the user, both in terms of cost and convenience, such as real-time journey planning and notification of disruptions (Poslad et al., 2015; Shaheen et al., 2017). Enabling the user to fully exploit these incentives requires development of the skills needed to use the relevant apps and online platforms.

Yeboah et al. (2018) have reported on the growth in the use of internet sites and mobile apps for information-seeking in the transport realm, indicating a generally good understanding of their use on the part of the general citizenry. Growth in internet literacy may also have beneficial impacts on the take-up of emerging transport technologies; for example, Copsey et al. (2016) cite a Passenger Focus study which found the following barriers to the use of public transport:

- passengers dislike being required to use cash on the bus, and in particular to tender the exact amount

- with stage-based tariffs, it is difficult for new and occasional passengers to assess the correct fare before boarding

- passengers who have to use more than one route (including changing forms of transport) are often charged higher fares than if a through service were available

- passengers dislike buying return tickets that may not be used or valid on the return journey

Mobile or e-ticketing is suggested as a response to many of these barriers, but may only represent a significant benefit where users have access to a smartphone, are able to use the relevant app and trust the service with their financial information.

A second consideration is that the development of a cadre of people with appropriate internet skills is critical for the emerging digital transport network, since fully capitalising upon the benefits generated by internet technologies (improved communications, safety and security etc.) requires a multi-layered network of proficiencies, including programming, design, data management, user interaction, cyber-security and data analytics (Ecorys UK Ltd, 2016). Current research indicates that the UK has a skills gap in many of these areas, with particular deficiencies in high-level digital skills such as cyber-security, cloud- and mobile computing, and data analytics (House of Commons Science and Technology Committee, 2017; TSC, 2016a). These deficiencies are worrisome not only for their effects on the UK's ability to fully embrace the benefits of digital technology, but also for their economic impacts, with Barclays' *UK Digital Development Index 2017* (Barclays, 2017) estimating that the digital skills gap may account for an estimated cost to the UK's economy of up to £63 billion a year. Addressing these gaps will require a range of approaches, from improved education and training in schools and universities, through to opportunities for advanced training in the workplace. Efforts will also be needed to identify emerging needs in the digital sphere, with concomitant investment in addressing these needs through education, training and apprenticeship programmes.

Impacts on the transport sector and research needs

While innovations in user-oriented technologies are a key factor in enabling emerging transport systems, the actual benefits they confer will rely on the willingness and ability of potential users to adopt them. Fully exploiting MaaS, for example, will require that the user interface is clearly and sensibly designed so that users fully understand its capabilities. This, in turn, will require the presence of digital skills from both the users and designers of such systems (Cohen et al., 2017). Currently, there is insufficient evidence available on the relationship between user engagement and the adoption of digital technologies in the transport realm, and on the design requirements necessary to enable this to occur. Further exploration of the relationships between the digital skills of users and the underlying skills necessary for effective design is needed to encourage more widespread uptake.

While the underlying skills of users are generally adequate for finding relevant information for their journey, the underlying skills needed to develop apps and services that are clear, useable and accurate are perhaps more limited. Additional investment and encouragement are needed to support the skills required for planning, developing and implementing useful and reliable services, particularly those related to data analysis and modelling, user interaction design and testing, and evaluation of impacts, particularly in the light of the increased demand for these and related skills in the transport and distribution sector (Dolphin, 2015; see also Figure 3).

Figure 3: Firms saying that the proportion of employees using certain skills has increased in the last two years, by industrial sector (net % of firms)

	Maths skills	Reading or writing more than four pages of text	Using computers	Mechanical or technical skills
Manufacturing	38	39	45	45
Construction	39	43	44	41
Retail	35	38	53	32
Financial services	49	55	71	32
Hospitality and leisure	30	37	45	36
Accountancy	47	58	71	34
Legal	40	65	78	36
IT and telecoms	47	56	70	35
Media, marketing, PR and sales	33	50	72	31
Education	40	58	64	35
Transportation and distribution	36	37	49	43
Real estate	45	65	75	37
Other	37	49	60	36

Source: Dolphin, 2015

Future considerations

The likelihood that technical computing and design skills will increasingly be required for efficient and effective implementation of future transport systems is great. As noted above, developments in AVs, emerging vehicle design considerations, and the integration of data resources and planning processes require an increasingly technical set of interdisciplinary skills, combined with their application in the social and public sector. New training programmes in data science, data management, intelligent mobility and materials sciences are emerging, but further consideration needs to be given to the training of researchers and practitioners, taking into account necessary skills such as data management, cyber-security, power systems and dynamic modelling.

5. The changing use of data in the transport system

In 2017, the UK received the top ranking from the Open Data Barometer in meeting the principles of the 2013 Open Data Charter, which include data releases that are: open by default; timely and comprehensive; accessible and usable; comparable and interoperable; for improved governance and citizen engagement; and for inclusive development and innovation (Open Data Barometer, 2017). As a signatory to the Open Data Charter, the UK government has worked to implement policies that support open data (Heimstädt et al., 2014), and has made great strides in developing open-data resources across a wide variety of sectors, including business and economy, crime and justice, education, environment, government, society and transport. In addition to endeavouring to achieve open data across government services, the UK has also made extensive investments in sourcing and making available pertinent commercial data, through such initiatives as the ESRC-funded Consumer Data Research Centre (CDRC), Urban Big Data Centre (UBDC), and Business and Local Government Data Research Centre (BLG). Such initiatives highlight the importance attached to access to relevant data resources by researchers, government services, technology developers and citizens. Coupled with the rapid emergence of open-source and freely available software for data analytics, the availability of these datasets presents expanding opportunities for more fully incorporating data into evidence-based decision-making processes.

The rapid emergence of mobile sensors and the internet of things (IoT) also plays a contributory role, particularly for transport data. User-based devices[3] (such as smartphones and quantified-self technologies), increased use of mobile social media, and the rising number of environmental sensors (such as pedestrian and cyclist counters) are adding rich sources of data to the transport-modelling landscape, particularly for previously under-represented groups and modes (Misra et al., 2014; Le Dantec et al., 2015; Cottrill et al., 2017; Hong et al., 2018). The availability of such data is beneficial for transport planning purposes, offering as it does a more representative and fine-grained understanding of movements of vehicles, people and freight through the transport network.

Of note, however, is the need to further consider the proprietorial standards of data, as interoperability is a key factor in integrating a wide spectrum of data from multiple sources across multiple platforms (Zhang et al., 2015). This challenge is thus far still open, as noted by Ahlgren et al. (2016) in relation to the IoT community, who state that:

> ‘Various communication standards and protocols have been suggested in the community, and some have been adopted in different IoT devices. However, there are also quite a few proprietary protocols and cloud services in the IoT, which make the interoperability and sharing of data across different devices and platforms quite challenging.’

Such challenges reinforce the need to focus not only on the acquisition of data itself, but also on people skilled in its management and analysis. This is supported by the growing use of data from a large variety of sources that may not previously have been considered in the transport

[3] Quantified-self technologies are devices such as sensors and other wearable technologies that collect data on aspects of the wearer’s life, especially related to health and fitness.

sector, such as social media data (Grant-Muller et al., 2014; Gu et al., 2016; Cottrill et al., 2017), smartphone data (Cottrill et al., 2013; Carrel et al., 2015; Vlassenroot et al., 2015) and weather data (Wang et al., 2015). Moving away from traditional silos of origin–destination studies and travel surveys in the era of widely available, open-data sources will require a deeper understanding of the mechanics of data processing and integration than ever before.

Impacts on the transport sector and research needs

The availability of such a rich array of data sources is critical for the further development of digital transport systems in the UK, as well as for the design of comprehensive transport networks that are responsive to the movement of people and goods through the landscape. More fully incorporating these resources into current practice, through training and continued attention to the development of comprehensive resources, will be critical for ensuring that their full benefits are gained. Additional research into how emerging data sources may be incorporated into existing activities – for example, exploring the incorporation of data generated by social media into transport models and planning practices (Cottrill et al., 2017; Golightly and Houghton, 2018; Zhang et al., 2018) – will be key to fully benefiting from the resources available. Applications in MaaS services, for instance, will require more robust integration of both traditional data sources (such as route-planning resources and public transport timetables) and emerging sources, such as social media and newsfeed data for factors that may influence routing, including weather conditions and data regarding the availability of shared vehicles. Since such sources may be open or public data, or proprietary ‘private’ datasets, further research into mechanisms for their access, integration and use is critical.

Making full use of such opportunities will also necessitate the development of people with the training and skills required to undertake such work. While the UK has demonstrated a commitment to making the necessary data resources available, ensuring that we have an adequately trained workforce to undertake the work needed to make sense of this data in useful and beneficial ways is also a key emerging need.

Finally, the management of data resources, particularly with reference to privacy and security in the light of the General Data Protection Regulation (EU, 2016a) and the EU directive on the security of networks and information systems (EU, 2016b), will also be a critical skill in the evolving transport landscape. Such issues have been of particular relevance in the area of AVs, given concerns regarding the sharing of personal information with developers and other vehicles, and the potential for data to be hacked. Location data is quite revealing of personal identity, given the relative likelihood of regular trips being made (e.g. between home and work or home and school) (Puttaswamy et al., 2014; Cottrill and Thakuriah, 2015). Consequently, ensuring that privacy is considered as a key part of working with geospatial or location-sensing data will be critical in ensuring trust on the part of the travelling public. This point is confirmed by the GDPR, which now considers ‘personal data’ to include location.

6. Conclusions

The transport ecosystem is a highly complex one, involving a wide range of public and private service providers along with physical and digital infrastructure, and the emergence of digital technologies has seen the sector evolve rapidly over the past few decades. The impacts of digital technologies in the transport sector cover a myriad of areas, including information provision and communication, supply chains and logistics, agent-based transport models, and new vehicle and service models (Shaheen and Chan, 2015; TSC, 2016c; Wong et al., 2017; Speranza, 2018). In order to fully realise the benefits of these emerging technologies in the transport sector, however, the considerations and concerns identified above in the areas of digital services, digital skills, and data and analysis must be addressed. TSC, for example, has identified a potential skills gap of 742,000 people by 2025, and suggests that approximately 1.159 million individuals will be needed, with an estimated supply of 417,000 (TSC, 2016a). Such findings are concerning, particularly given the increasing focus on AVs and MaaS as new ways forward in the transport environment.

A number of key concerns and research gaps have been identified above, with the following emerging most strongly from the review of policy and academic literature:

- digital divides represent a growing concern for the widespread implementation of robust, reliable digital transport networks. Further research is needed to evaluate the spatial implications of such divides, along with how they may be most efficiently addressed

- the development of adequate digital skills across the user base will be critical to ensure widespread uptake of digital transport services (such as MaaS) and the benefits they confer

- the development of a workforce with more targeted digital skills will likewise be critical for ensuring the continuing design and implementation of digital transport systems. In addition to traditional engineering and modelling skills, app development, user interaction design, data analytics, digital security and data integration design will be core needs for ensuring continuing growth in the transport market

- data will continue to be a key component of transport network design, development and implementation; however, how we manage and collate such data will become increasingly important, given the integral nature of this resource. Ensuring adequate skills development in both the use and management of data, in addition to its integration with emerging transport models, will require investment in workforce training, as well as an expanded understanding of the skills needed in the transport sector

It is clearly a critical time in the development of the digital transport system in the UK, with great potential emerging. However, for us to fully realise the benefits open to us, we must increase our efforts to ensure a reliable, comprehensive network of technology and data, as well as the skilled personnel necessary to develop, design and evaluate the system.

7. Appendix: Methodology

To conduct this research, a rapid evidence review of the literature, supported by extensive reports from government agencies and relevant non-profit-sector agencies was undertaken, supported by the use of Google Scholar and the University of Aberdeen's online library. The review was primarily limited to the last 10 years, though where necessary older research has been consulted. Terms and phrases used for conducting the review included: transport, digital, 'United Kingdom', 'digitisation in the United Kingdom', 'mobility as a service', 'autonomous vehicles', data, and 'user engagement'. Various combinations of these terms provided the groundwork for identifying relevant literature, with further resources identified through reference to similar works, reviews of citation lists and recommended related articles.

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