2018/19 ECR Project

A City-Level Digital Twin Experiment for Exploring the Impacts of Digital Transformation on Journeys to Work in the Cambridge Sub-region

Final Reporting

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Abstract

The project explores the possible impacts of digital transformation on journeys to work through the development of a city-level digital twin (CDT) prototype that integrates data, models and insights from multiple disciplines and sectors. The research includes three work packages, 1) empirical investigation of key factors affecting worker's choice on place of work (e.g. fixed workplace, work at/from home) and on travel mode in the Cambridge sub-region; 2) developing a digital twin prototype including a web-based interface for simulating journeys to work and testing two digital transformation scenarios (prevalence of teleworking, large-scale adoption of electric vehicles); 3) engaging with local authorities, modelling experts and other key stakeholders to collect feedback on the application and future development of CDT. A productive partnership has been established between the local authorities and the project team for the co-development of the digital twin prototype. The project also collaborates closely with academics at UCL and Cambridge. Key research outputs are discussed in detail and a series of working propositions are proposed, which may guide the future research on CDT.

1 Introduction

We are living through the “4th Industrial Revolution”, moving from a period of relative data scarcity to an era of ‘digital abundance’. The sheer size of investments and efforts for building “smart cities” across the globe has epitomized the inspiration for future better cities in the digital era. In the UK, the National Infrastructure Commission has outlined an ambitious plan of building a national “digital twin” of UK infrastructure, which aims to demonstrate UK’s global leadership in smart infrastructure. The digital twin brings together individual infrastructure models and the interdependencies between them through a federated system, thus represents a coordinated approach for planning, constructing and managing national infrastructure. The potential benefits of the national digital twin are apparent – optimising use of resources, reducing service disruption, increasing resilience and boosting quality of life for citizens, but how to materialise such benefits through effective policy making remains a big challenge ahead.

While the digital twin technology is making great strides in the UK with several large-scale pilots under construction (e.g. Exeter, Bristol, Queen Elizabeth Park in London) or being considered (e.g. Smart Cambridge), the varying and changing socio-economic and political context of the UK cities implies that the digital twin alone is unlikely to be a one-size-fits-all solution to city challenges. For example, while congestion has been regarded as a prevailing issue across major cities, there are actually 20% fewer commuting journeys per person per week in the UK in 2016 than the mid-1990[1]. This trend has often been attributed to a wide range of transformations regarding the nature of employment such as more part-time work, more people working from multiple places (e.g. teleworking), increasing self-employment (e.g. the “gig” economy), etc. Such behavioural changes are complex and will have profound implications on how we plan, use and manage our future infrastructure. However, understanding such changes requires an inter-disciplinary and collaborative approach. The digital twin has great potential for bridging the disciplinary and professional gaps by incorporating data and insights from multiple sectors, thus fostering stakeholder debates over complex trade-offs.

The project represents an early trial to address the research gap on city-level digital twins. It aims to develop a digital twin model prototype for examining the potential impacts of digital transformation on journeys to work in the Cambridge sub-region. The report is organised as follows. Section 2 introduces the study area. Section 3 discusses the key research outputs. Section 4 summarises the potential contributions to a digital built Britain through proposing a series of propositions for guiding future research.

2 Overview of the study area

The core study area for this study is the Cambridgeshire and Peterborough Combined Authority, which consists of 6 Local authority districts[2]. Given the relatively large commuting catchment of Cambridge, the modelling area is expanded to cover the former Greater Cambridge and Greater Peterborough LEP area, which consists of 14 local authority districts. The study area features the fast-growing southern areas (i.e. Cambridge and South Cambridgeshire) and the deprived northern areas in the Fens, which represents a typical UK city region of significant spatial inequality. A map of the study area is presented in Figure 1.

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[1] Future of Travel Report by the Commission of Travel Demand (https://www.its.leeds.ac.uk/about/news/the-future-of-travel-demand/)

[2] The Cambridgeshire and Peterborough Combined Authority, as it stands in the time of writing this report, includes Cambridge, South Cambridgeshire, East Cambridgeshire, Fenland, Huntingdonshire and Peterborough.

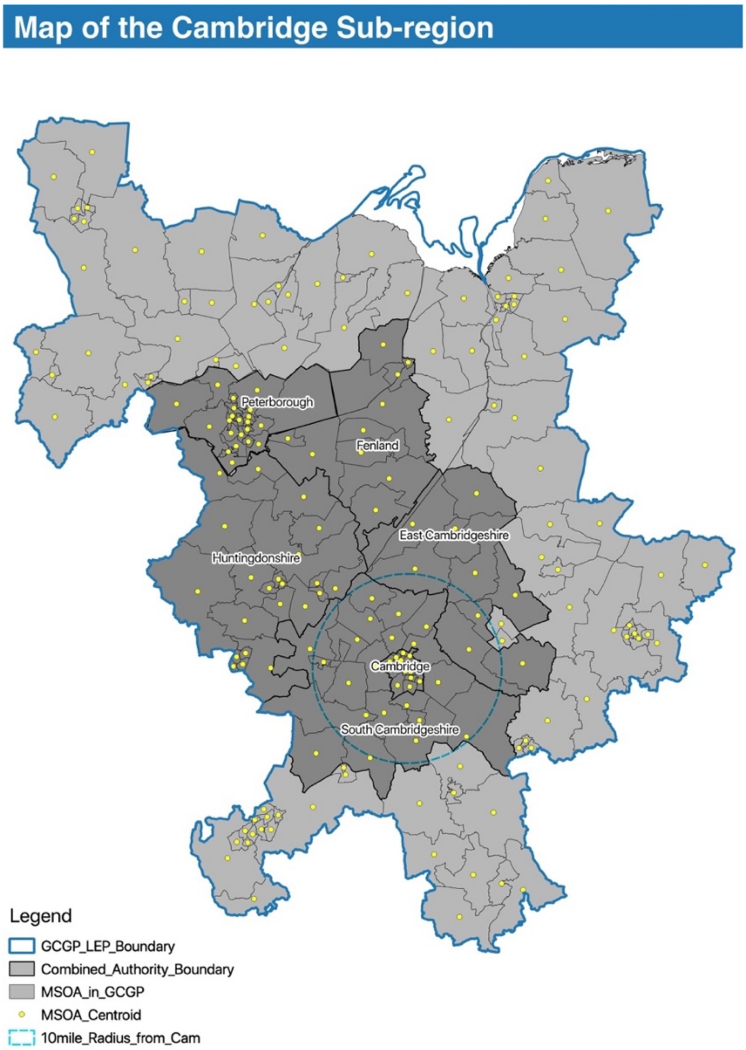
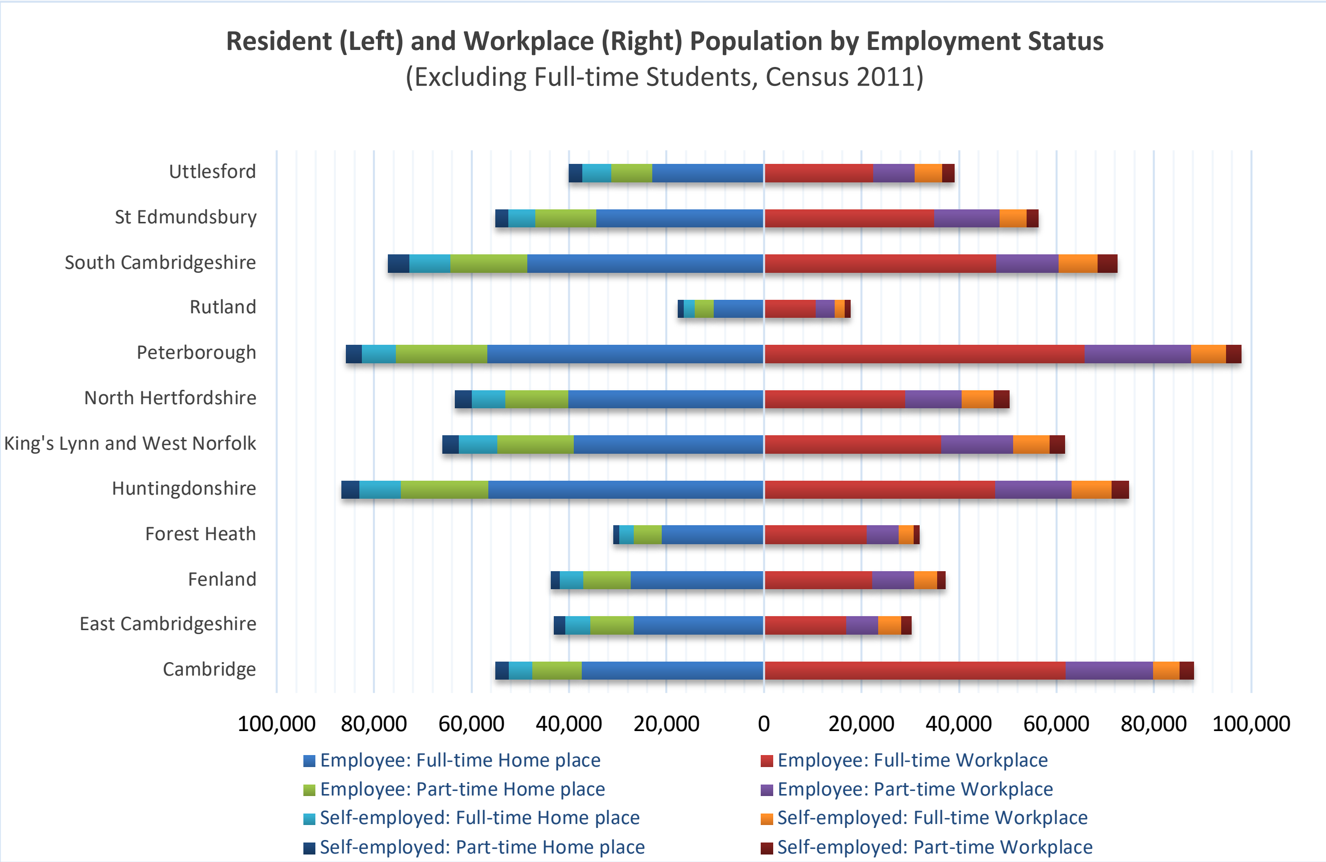


Figure 1 Map of the study area

Zones in dark grey: the core study area (Cambridgeshire and Peterborough Combined Authority)

In terms of the (im)balance between resident and workplace population in the study region (see Figure 2), Cambridge and Peterborough are the only two cities in the study area that have more employed workers than employed residents, indicating that workers from other local authorities may have to commute to Cambridge and Peterborough for work.

Figure 2 Resident and workplace population by employment status

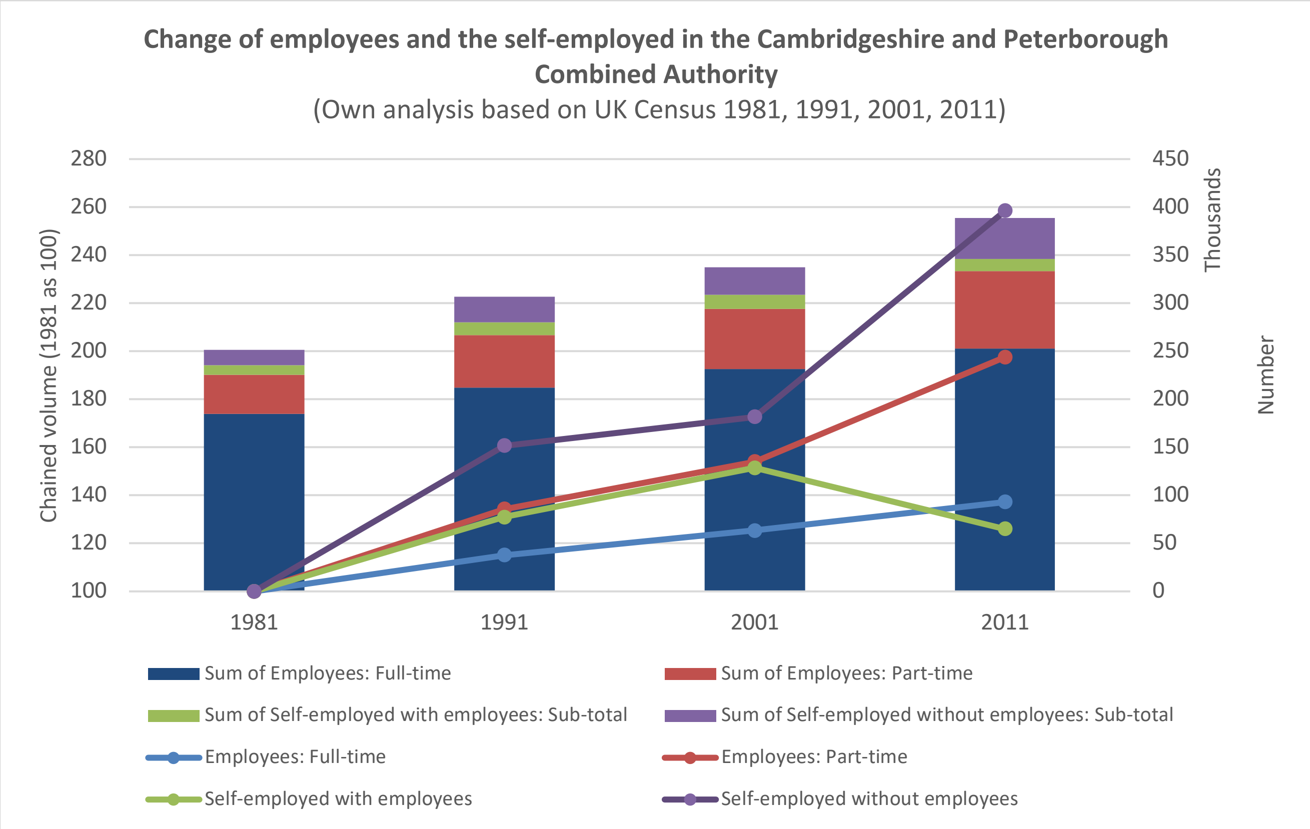


3 Key research outputs

3.1 Trend in employment growth

The investigation of historic data on employment growth by type (see figure below) shows that, the part-time employees and the 'self-employed without employees' have been growing faster than other employment types in the Cambridgeshire and Peterborough Combined Authority. Compared with 1981, the number of self-employed without employees has grown 2.6 times and the part-time employees have nearly doubled in 2011. In particular, the self-employed without employees (who may be closely related to the 'gig economy') see an ever-quicker growth during 2001-2011 in the study area. The full-time employees, who account for 65% of the workforce in 2011, have seen a steady growth since 1981. It can be anticipated that the share of part-time workers including both employees and the self-employed is likely to raise in the study area, supposing the observed trend continues. As more people start to engage flexible working (e.g. flexible working hours, working from multiple places), it is important to investigate the associated impacts on the choice of place of work and journeys to work.

Figure 3 Change of employees and the self-employed in the Cambridgeshire and Peterborough Combined Authority



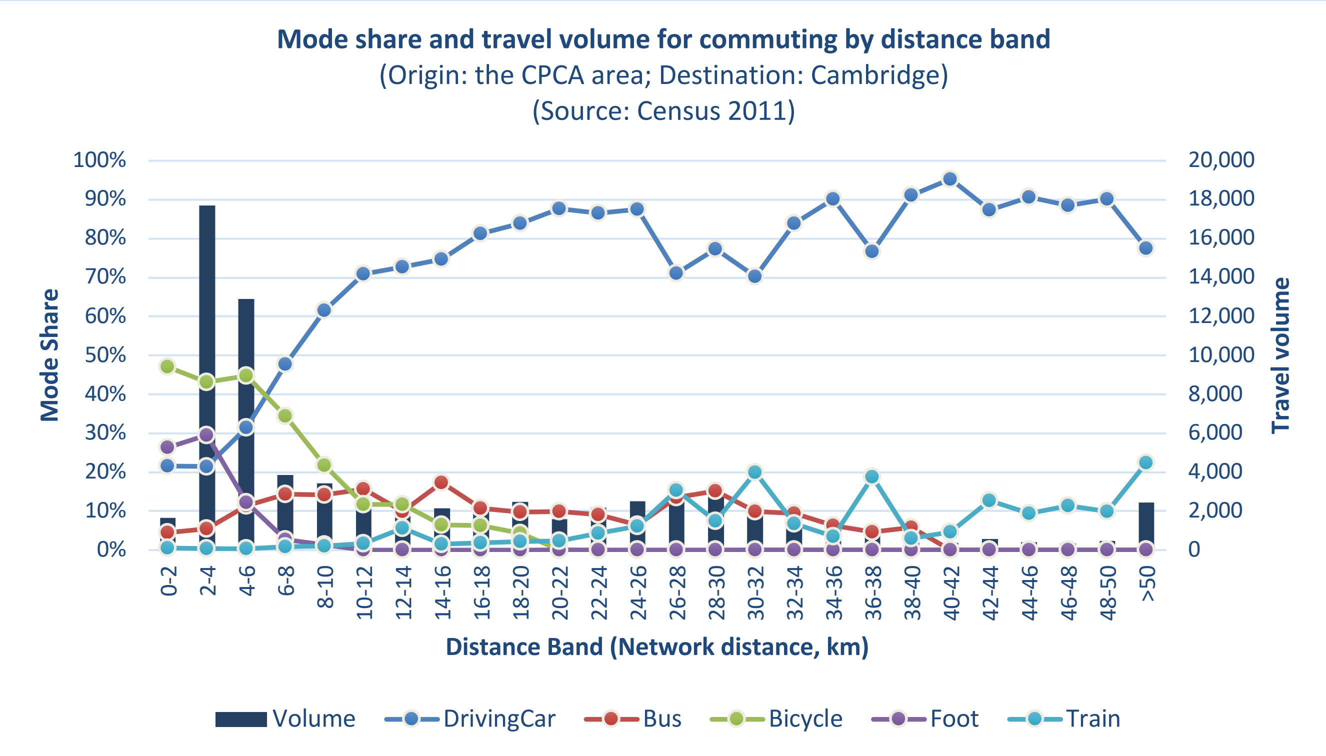
3.2 Understanding the choice of place of work

Our statistical analysis using Census 2011 microdata for the study region confirms that being a self-employed (either as a freelancer or with employees) is more likely to 'work at/from home' or have 'no fixed place' than being an employee, after controlling the cross-sample differences on age, socio-economic status, industry of work, broad residence location, length of working hours, possible childcare duty and housing condition (measured by number of persons per room). Specifically, the positive correlation between the age of individual sample and the choice of working at/from home indicates a propensity for working at/from home when workers get old in the study area. Higher socio-economic status would increase the probability of choosing home working. It suggests that high-skill jobs (e.g. managerial and professional) are more amenable to working at/from home than relatively low-skill jobs (e.g. semi-routine and routine). Low-skill jobs are more likely to have 'no fixed workplace'. We also find that the choice of home working is subject to the availability of space in the house – as the number of persons per room increases, i.e. higher occupancy level, the likelihood of working at/from home decreases in the study region. The interdependence between home working and housing provision, subject to further tests using up-to-date data, may shed a new light on understanding worker's choice of place of work.

3.3 Understanding the mode choice for journeys to work

The figure below shows the mode share for commuting from the CPCA area to Cambridge as the workplace using 2011 Census data, segmented by a 2-km distance interval. Note that 'Driving Car' includes only 'driving in a car/van' and exclude commuters who are passengers in car[3]. The figure also omits other modes of travel ('motorcycle; scooter or moped', 'taxi' as by Census 2011 definition)[4].

Figure 4 Mode share and travel volume for commuting by distance band



It shows that for distance under 6 km, the predominant mode for commuting to Cambridge (including those commuting within Cambridge) is bicycle (around 45%), followed by walking and driving. However the mode share for driving increases sharply from 4 km, reaching about 50% for 6-8 km and a striking 70% for 10-12 km. This is accompanied by the quick drop of bicycle mode – it is not surprising as cycling over 8 km (about 24 min one-way for an average speed of 20 km/hr) on a daily basis may become physically undesirable. Less than 10% of commuters use bus for communing within the 0-4 km range. The share of bus increases from 4 km but is capped around 17% at around 15 km. The share of train for commuting remains under 10% for distance under 27 km, with a spike around 12-14 km range (e.g. Waterbeach - Cambridge), and increases to about 20% for 26-28 km (e.g. Newmarket/Royston – Cambridge) and 30-32 km (e.g. Ely – Cambridge).

Given the local policy goal of reducing car dependence and promote sustainable travel, the shift from car to bus and other non-motor modes has been the overarching focus in local transport strategy. The figure below shows the ratio of mode share between bus and car around Cambridge – the purpose of producing the map is to emphasize the spatial heterogeneity in terms of the mode choice of car and public transit. To address the desirable shift from car to bus, the 5-15 km commuting distance range is selected, within which the bus remains a feasible substitute to car for commuting purpose. For

[3] Commuters as passengers in car account for about 3.9% of all commuters to Cambridge including those commuting within Cambridge.
[4] All other modes account for about 1.6% of all commuters to Cambridge including those commuting within Cambridge. The exclusion thus does not change the analysis results significantly.

distance beyond 15 km, driving a car may become advantageous in terms of travel time. In Figure 5 a red line indicates that there is less than one bus commuter by every 100 car commuters along the commuting corridor; an orange line indicates that there are less than ten bus commuters by every 100 car commuters.

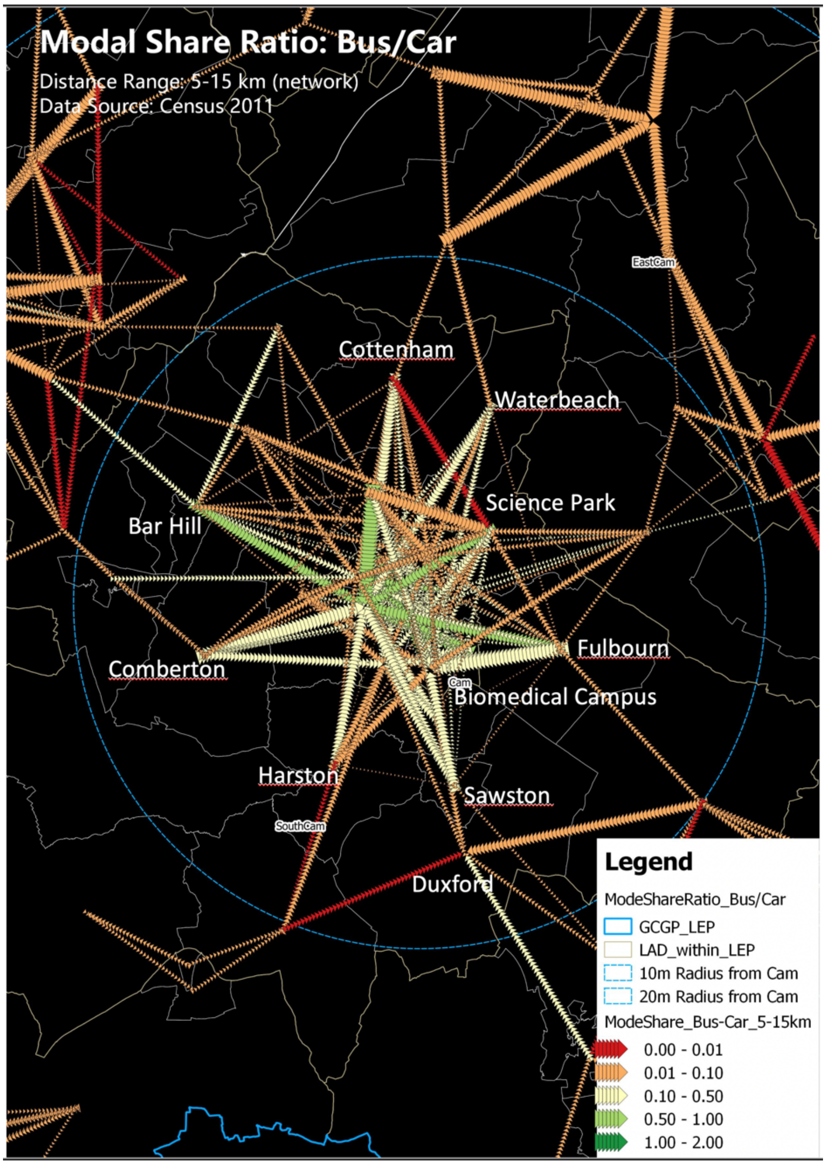


Figure 5 Modal share between bus and car for commuting purpose in Cambridge and the environs (Census 2011)

A red line indicates that there is less than one bus commuter by every 100 car commuters along the commuting corridor.

An orange line indicates that there are less than ten bus commuters by every 100 car commuters.

For major employment sites in central Cambridge, the mode ratio between bus and car is around 0.5-1.0, indicating that there are more than 50 bus commuters for every 100 car commuters – there is room for further improvement. For employment sites on the fringe, e.g. Science Park and the Biomedical Campus, the mode ratio between bus and car is generally under 0.1, indicating less than ten bus commuters by every 100 car commuters. The empirical finding suggests that, to shift commuters from car to public transit, the mobility solutions need to be more targeted in relation to specific locations and commuting corridors, and socio-economic background of commuters. The spatial and social dimension is very important in policy making, without which the behavioral changes expected from policy interventions (e.g. shift towards public transit) are difficult to fulfil.

3.4 Insights from a big data set – Automatic Number Plate Recognition (ANPR)

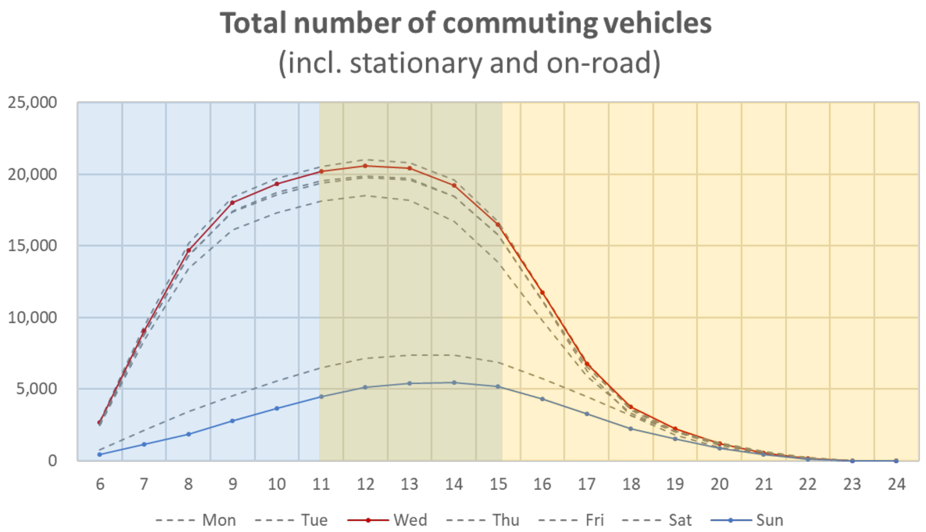
In addition to the conventional data sources, this research taps into a new big data set, namely the Automatic Number Plate Recognition (ANPR) records, to understand the hourly journeys-to-work patterns in Cambridge. The local authority is acknowledged for providing the anonymized ANPR data. The ANPR data set applied covers a whole week (Mon-Sun) in June 2017. To link the data with aggregate Census data, each ANPR camera is assigned to a Middle-layer Super Output Area (MSOA)[5], which is the spatial unit of analysis used in our study. During the one-week data collection period, around 510,000 vehicles per day can be identified that pass through or stop by Cambridge.

A set of rules are proposed to differentiate commuting cars from non-commuting car journeys (e.g. tourism and logistics). The following rules are applied for detecting a commuting car, which are derived from our own tests.

- A broad travel direction towards the city centre, determined by the captured trajectory of the vehicle;
- First-appearance time stamp between 6am-3pm;
- Duration of stay in Cambridge area no less than five hours.

Based on the rules reported above, approximately 21,000 vehicles per weekday on average are recognized as commuting vehicles. The following figure depicts the total number of commuting vehicles in Cambridge by the hour, which includes both stationary and on-road vehicles. It shows that the total number of commuting cars peaks at noon in Cambridge.

Figure 6 Hourly total number of commuting vehicles in Cambridge (including both stationary and on-road vehicles)



Commuting load by the hour excluding stationary cars can also be obtained from the records (see Figure 7). The processed data shows that morning peak in Cambridge is between 7-8am, while the afternoon peak is 4-5pm. The commuting pattern on Friday is slightly different from the other workdays, with lower volume in both morning and afternoon peak. A detailed investigation into the Cambridge Biomedical Campus (CBC) yields some local insights (see Figure 8). For instance, majority of workers at CBC tend to come to work at 7am, leading to a single-point morning peak. However, the afternoon peak at CBS seems to be more spread than the city as a whole, with more workers remain at workplace after 5pm. We deem that such a load pattern is related to the particular working schedule

[5] Middle-layer Super Output Area (MSOA) is an official Census geography. More information can be found at ONS website.

of hospital workers, such as changing shift in the morning. To further understand the pattern, the mode share by socio-economic group (SEG) at the Cambridge Biomedical Campus (CBC) in Census 2011 is presented in Figure 9. Although the two data are for different years, the composition of car commuters by SEG in 2011 suggests that the SEG4 (semi-routine and routine workers, such as carers, cleaners) accounts for a rather small share of car users – it is the medium-to-high skill workers contribute to the observed commuting pattern as revealed by the ANPR data. Cycling seems to be a privilege for the high-skill workers, which is in line with the findings in London. The low share of bus implies that, to encourage public transit, local bus services need to be tailored to meet the particular mobility requirements of CBC workers.

Figure 7 Commuting load by hour in Cambridge

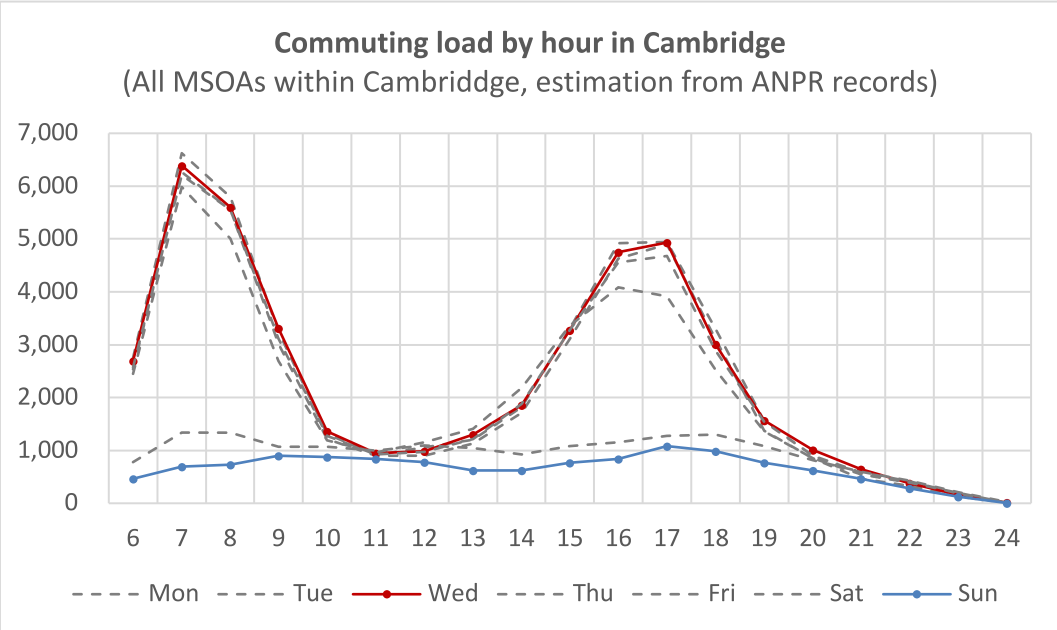


Figure 8 Commuting load by hour at the Cambridge Biomedical Campus

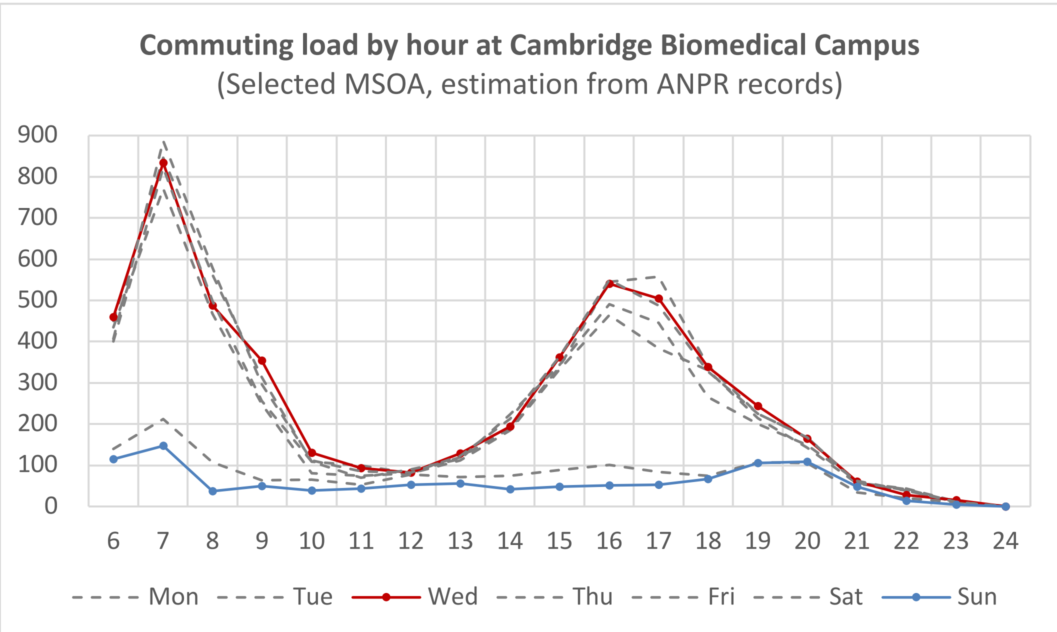
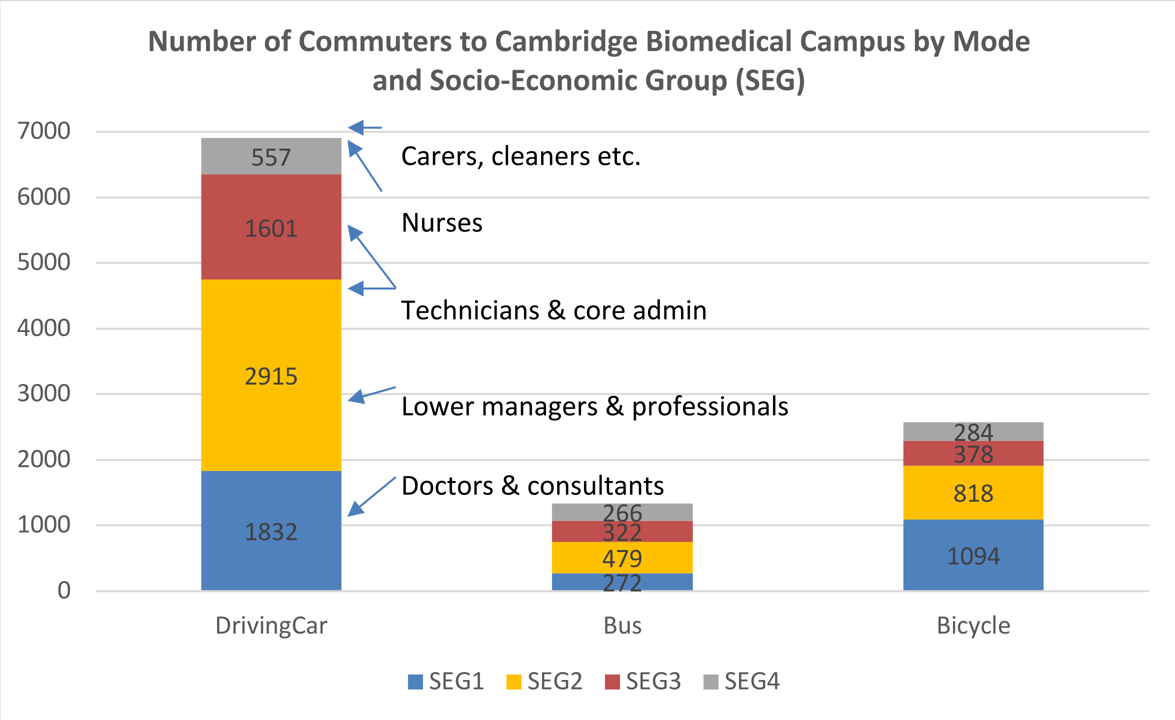


Figure 9 Number of commuters to Cambridge Biomedical Campus by mode and Socio-Economic Group (SEG)



The ANPR data represents one of the emerging big data sources in cities, which sheds a new light on the spatial-temporal heterogeneity of vehicle use. The typical challenge of working with similar data (e.g. traffic count data, travel card data) remains – the lack of socio-economic information of the samples makes it difficult to understand the underlying causes of the observed pattern. Linking the data with more structured data such as the Census may help address the analytical difficulty.

3.5 A digital platform for understanding journeys to work in the Cambridge sub-region

One of the main analytical difficulties for understanding journeys to work is the high-dimension feature of the travel data – travel origin, destination, mode, distance/time, social-economic classification, household profile etc. As proposed in the proposal, a web-based digital platform is developed to visualize the multi-dimensional journeys to work data. To prepare the data set, we build on the open-access Census 2011 flow data for the study area, which include origin and destination by travel mode or National Statistics Socio-economic Classification (NS-SEC)[6]. The original flow data is then expanded by adding the breakdown of NS-SEC by mode through an established land-use and transport model application for the Cambridge sub-region[7]. The expanded data set thus include origin, destination, travel mode and socio-economic classification. The socio-economic segmentation in the data set, which is aggregated from NS-SEC, is summarized in the table below. From SEG1 to SEG4, it indicates a decreasing ranking in grade.

[6] Detail information about the structure and methodology of NS-SEC can be found at ONS website.
[7] The model application is developed for the Cambridgeshire and Peterborough Independent Economic Review (CPIER) and funded by the Cambridgeshire and Peterborough Combined Authority and Cambridge Ahead. The CPIER final report, which summarises the model-based policy analysis, can be downloaded here.

Table 1 Model segmentation on socio-economic classification

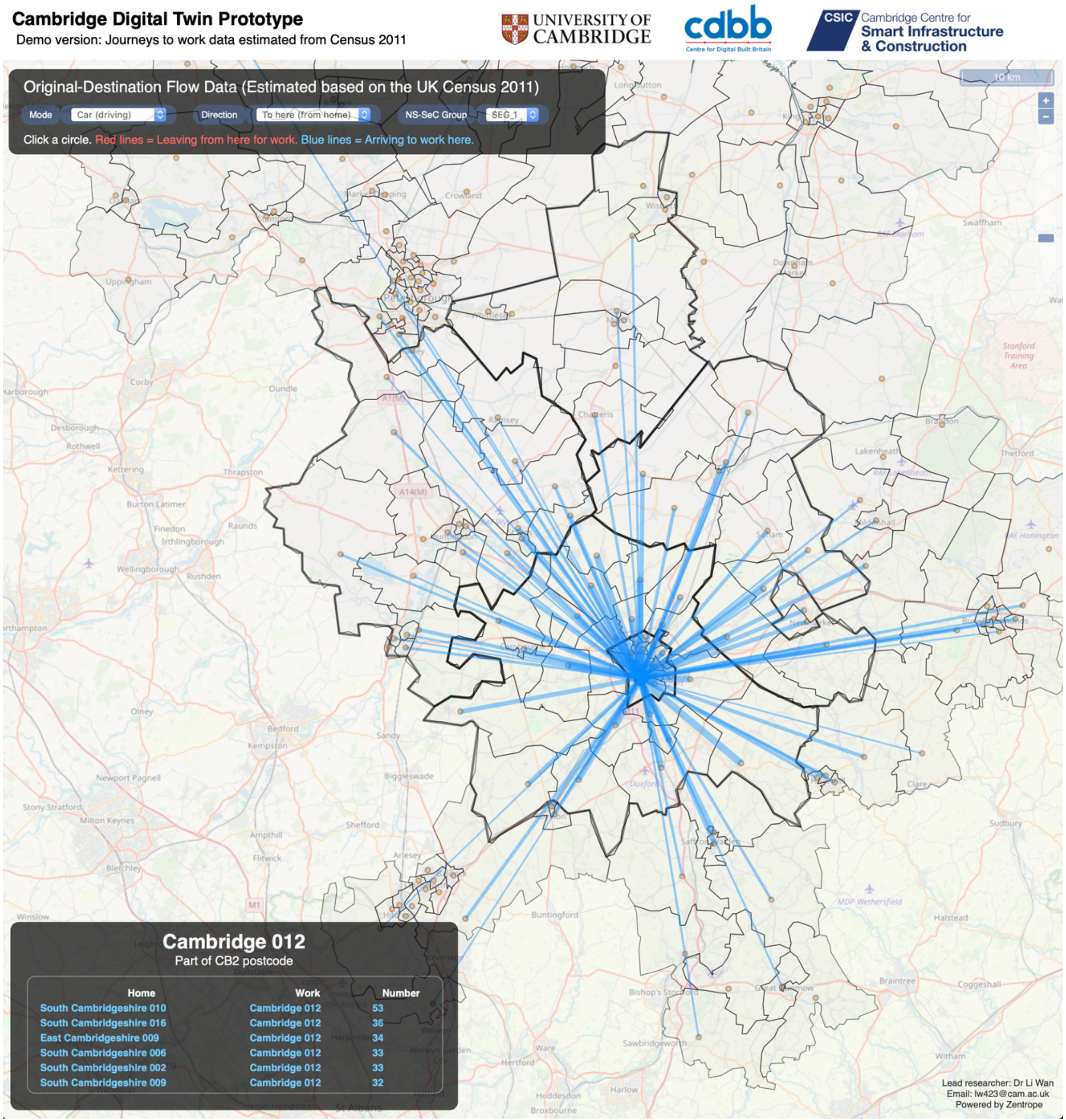
Model SEG	Census NS-SeC Code (SOC2010 rebased)	Description of occupation / activity
1	1	Higher managerial and professionals
2	2	Lower managerial and professionals
3	3	Intermediate
	4	Small employers and own account
	5	Lower supervisory
4	6	Semi-routine
	7	Routine

Based on the expanded journeys to work data set, a web-based digital platform is developed. Users can view the commuting flow departing from or arriving to any Middle-layer Super Output Area in the Cambridge sub-region and examines the breakdown by travel mode and socio-economic group. A hyper link for the digital platform is provided below.

Click to access the Digital Twin Prototype for Journeys to Work

The screenshot below shows the interface of the digital platform – it shows the commuting flow of higher managerial and professional workers (SEG1) driving to one of the Cambridge zones from the wider region.

Figure 10 Web-based user interface of the digital twin platform for journeys to work in the Cambridge sub-region

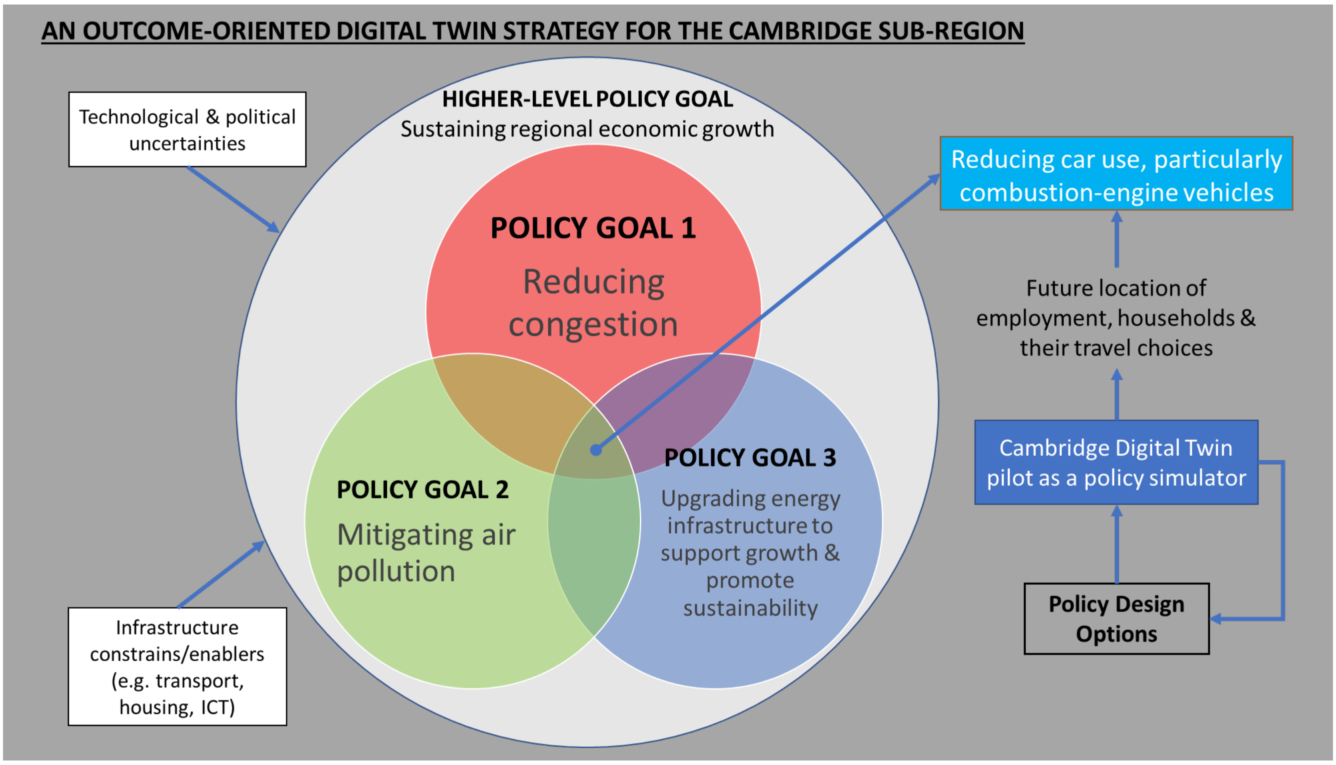


3.6 A digital twin model for simulating future journeys to work

As informed by the workshop outcomes with local authorities, the purpose of the Cambridge Digital Twin (CDT) model is to bridge the sectoral silos of transport, housing, environment and energy in local policy making. These policy themes are jointly selected by the local authorities and the research team as cross-cutting policy issues with local urgency.

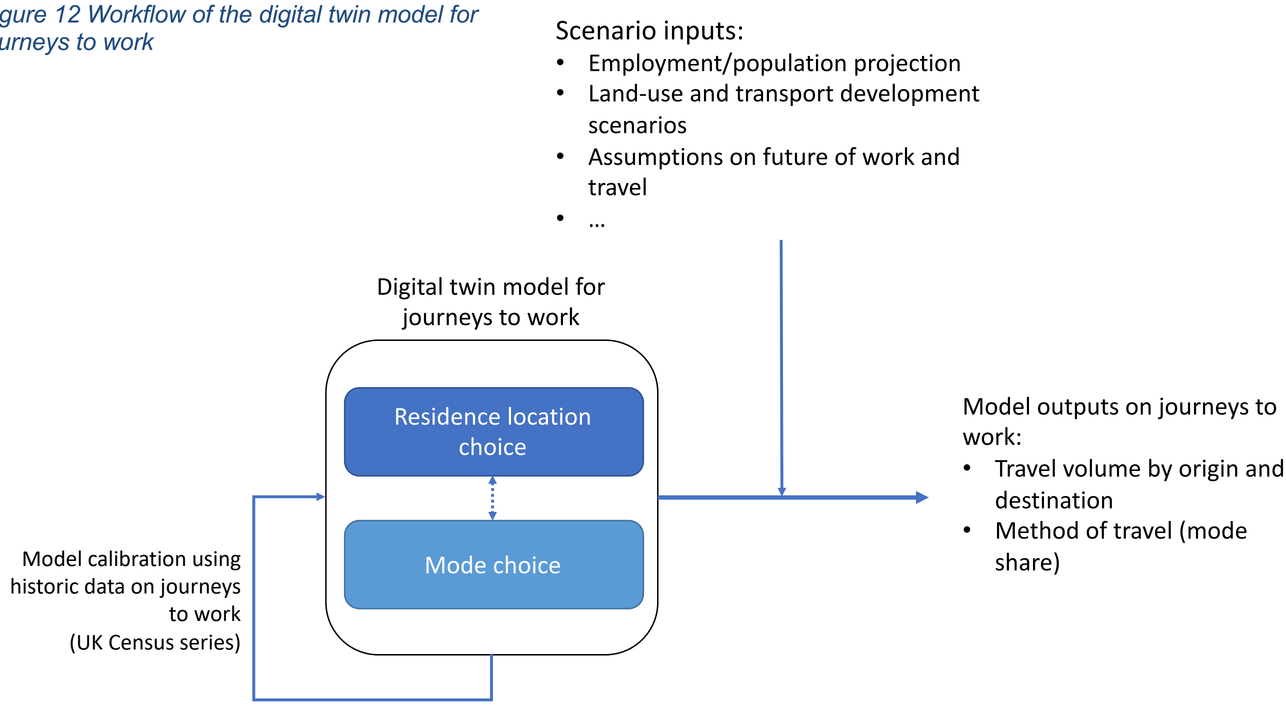
The model development follows a policy-oriented approach (see Figure 11). In terms of time horizon, the proposed CDT prototype is focused on the medium-to-long term policy scenarios. In terms of modelling scope, the CDT prototype aims to quantify some of the interdependences among transport, air quality, housing and energy infrastructure in the Cambridge sub-region in relation to background changes in employment and technology. It has been identified through workshop and interviews that the future location of businesses, employment, households and their travel choices is the pivot variable set that connects the selected policy themes.

Figure 11 A policy-outcome-oriented approach for developing the Cambridge digital twin prototype on journeys to work



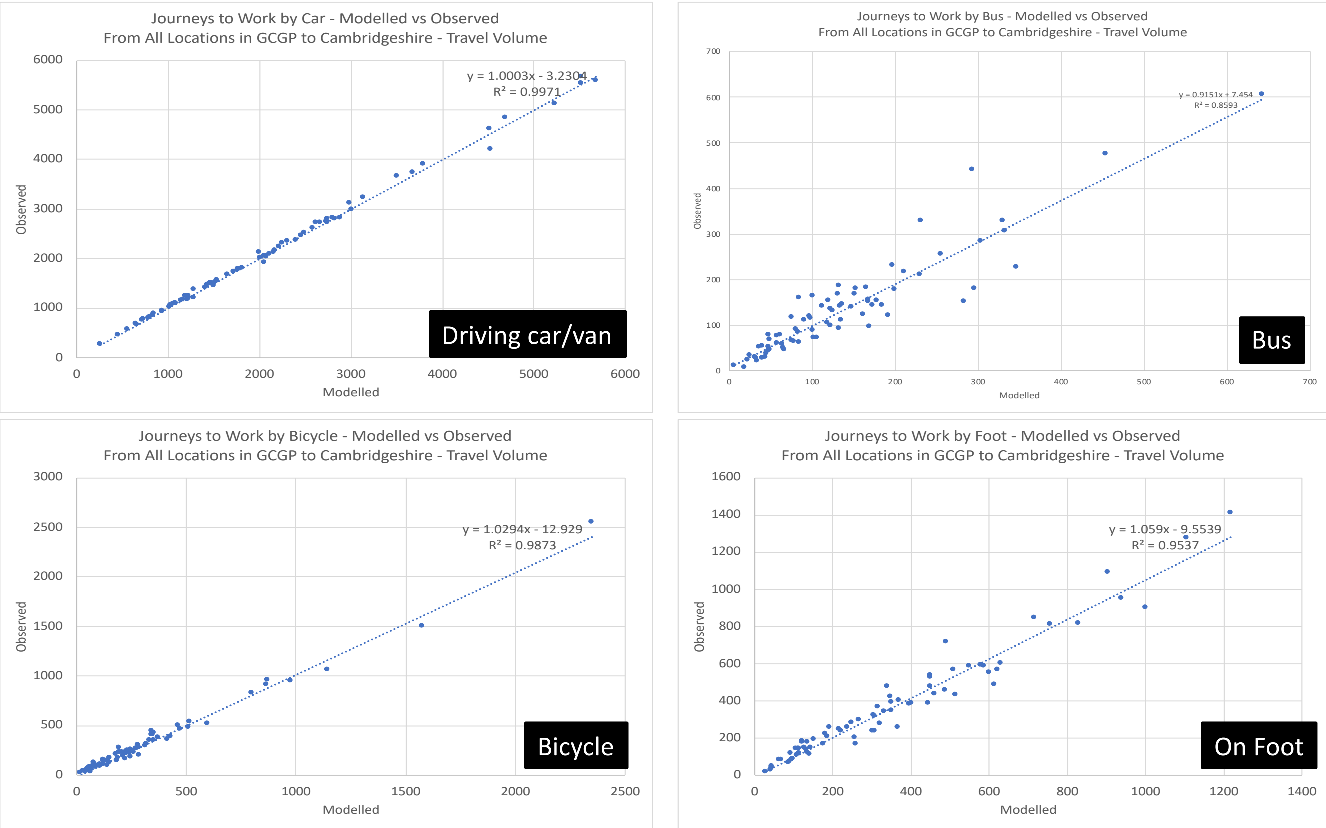
The CDT pilot is focused on commuting trips (e.g. journeys to work) which is a key determinant of peak-time travel demand. Based on the journeys to work data, a computational digital twin model is developed. The proposed digital twin model builds on established transport modelling methods and incorporates new explanatory variables relating to the type of employment and the built environment. The modelling workflow is summarized in Figure 12.

Figure 12 Workflow of the digital twin model for journeys to work



The digital twin mode consists of two inter-connected components, the residence location choice module and the mode choice module. The proposed model builds on established transport modelling method, and is expanded by adding new location-specific variables relating to local employment profile (e.g. share of the self-employed/part-time workers), dwelling density and occupancy level. Statistical analyses are applied to inform the selection of variables. The goodness of fit of the calibrated mode choice module is presented below.

Figure 13 Goodness of fit of the calibrated mode choice model - observed vs modelled number of commuters by mode (at workplace)



The calibrated model is then used in forecast mode to produce future journeys to work scenarios in the study region. Informed by the discussion with local authorities, two future scenarios are proposed to demonstrate the functionality of the digital twin model, 1) prevalence of teleworking, and 2) future electric vehicles charging demand, which are introduced in turn below.

Scenario 1: Teleworking

Teleworking or remote working represents a flexible way of working without commuting to a central workplace. Teleworking enables workers to work from home or other locations for some days of the week, which thus may reduce the overall commuting demand. One of the key modelling assumptions pertains to what kinds of employment are amenable to teleworking in the future (see Table 2). It is assumed that medium-to-high-skill jobs, self-employed jobs and clerical and administrative jobs are more prone to teleworking. Based on this assumption, the percentage of jobs subject to teleworking in the study area is summarized in Table 3 – a total of 14% of jobs (about 19,000 jobs based on the presented employment projection for Cambridge) are amendable to teleworking in Cambridge.

Table 2 Model assumption on future employment amenable to teleworking (as % of the workforce)

Model segmentation	National Statistics Socio-economic Classification	% Teleworking
SEG1	L1 Employers in large establishments	0%
SEG1	L2 Higher managerial and administrative occupations	0%
SEG1	L3.1 Traditional employees	20%
SEG1	L3.2 New employees	20%
SEG1	L3.3 Traditional self-employed	25%
SEG1	L3.4 New self-employed	25%
	L4 Lower professional and higher technical occupations	
SEG2	L4.1 Traditional employees	20%
SEG2	L4.2 New employees	20%
SEG2	L4.3 Traditional self-employed	25%
SEG2	L4.4 New self-employed	25%
SEG2	L5 Lower managerial and administrative occupations	20%
SEG2	L6 Higher supervisory occupations	20%
SEG3	L7.1 Intermediate clerical and administrative occupations	10%
SEG3	L7.2 Intermediate sales and service occupations	10%
SEG3	L7.3 Intermediate technical and auxiliary occupations	0%
SEG3	L7.4 Intermediate engineering occupations	0%
SEG3	L8.1 Employers in small establishments in industry, commerce, services etc.	0%
SEG3	L8.2 Employers in small establishments in agriculture	0%
SEG3	L9.1 Own account workers (non-professional)	0%
SEG3	L9.2 Own account workers (agriculture)	0%
SEG3	L10 Lower supervisory occupations	10%
	L11 Lower technical occupations	
SEG3	L11.1 Lower technical craft occupations	0%
SEG3	L11.2 Lower technical process operative occupations	0%
SEG4	L12.1 Semi-routine sales occupations	10%
SEG4	L12.2 Semi-routine service occupations	10%
SEG4	L12.3 Semi-routine technical occupations	10%
SEG4	L12.4 Semi-routine operative occupations	0%
SEG4	L12.5 Semi-routine agricultural occupations	0%
SEG4	L12.6 Semi-routine clerical occupations	20%
SEG4	L12.7 Semi-routine childcare occupations	0%
SEG4	L13.1 Routine sales and service occupations	10%
SEG4	L13.2 Routine production occupations	0%
SEG4	L13.3 Routine technical occupations	10%
SEG4	L13.4 Routine operative occupations	0%
SEG4	L13.5 Routine agricultural occupations	0%

Table 3 Number of jobs amenable to teleworking in Cambridgeshire

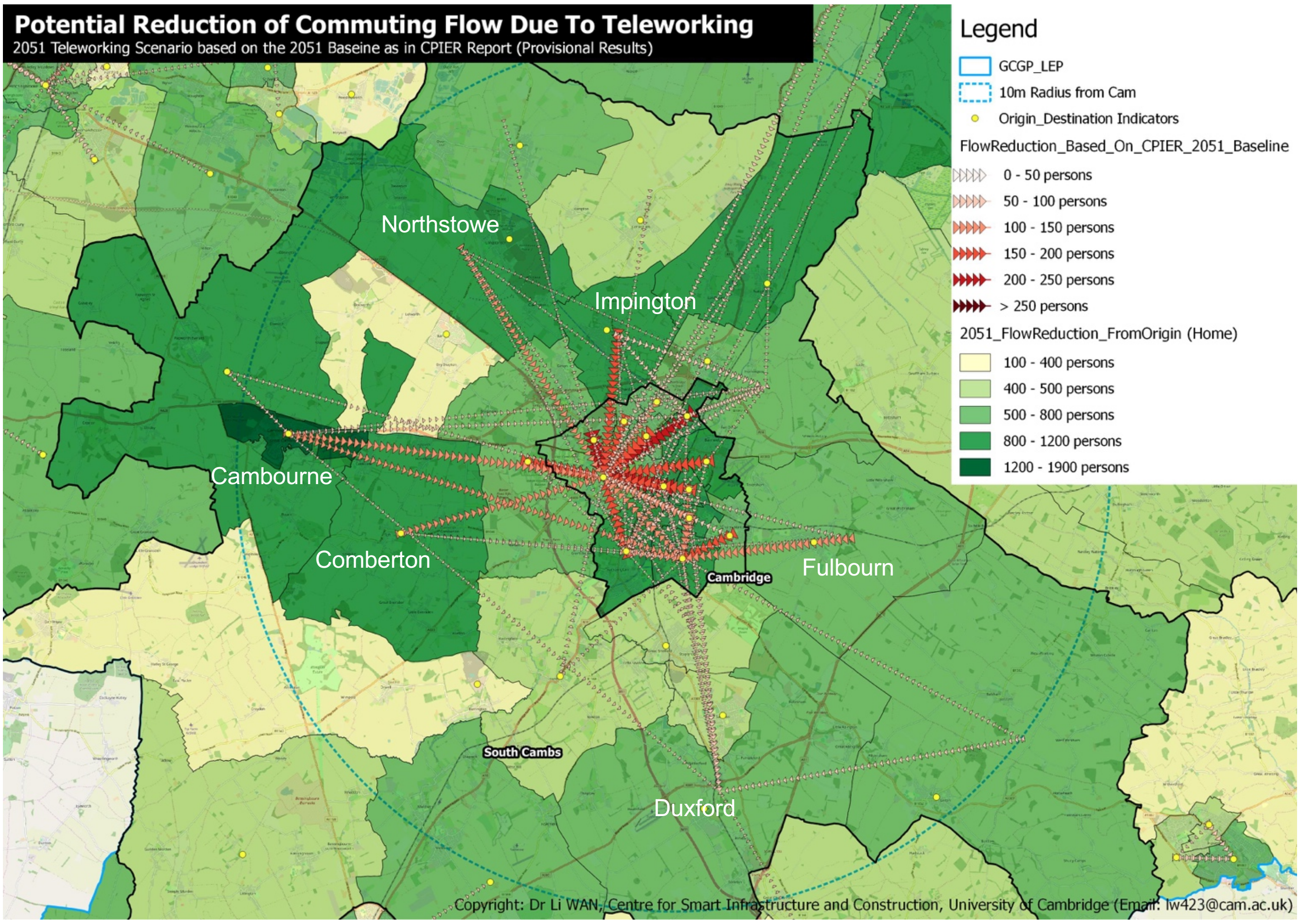
	Number of jobs amenable to teleworking					Employment (Growth rate, %pa*)		Employment sub. to teleworking
	SEG1	SEG2	SEG3	SEG4	SEG_Total	2011	2051	2051
Cambridge	18%	20%	6%	8%	14%	88,145	138,498 (1.1%)	19,112
South Cambridgeshire	17%	20%	4%	7%	12%	72,487	123,853 (1.3%)	14,804
East Cambridgeshire	16%	20%	4%	7%	10%	30,242	43,735 (0.9%)	4,233
Huntingdonshire	15%	20%	5%	7%	11%	74,793	100,365 (0.7%)	10,739
Fenland	14%	20%	4%	6%	8%	37,246	53,409 (0.9%)	4,491
Total						**302,913**	**459,860 (1.0%)**	**53,380**

* The employment growth assumption is in line with the scenario design as in the CPIER report (see footnote 5 on page 9 for more information about the CPIER report).

To test the possible impacts on commuting due to teleworking, a comparative scenario analysis is conducted. We first run the digital twin model to generate a baseline 2051 scenario for the study region, using the assumed employment projection summarized in Table 3. The baseline scenario serves as the basis for comparing the relative changes across scenarios. Recall that the proposed digital twin model can predict both the residence location choice and the mode choice. In the baseline scenario, both the residence location and the mode choices are simulated by the model.

Technically the prevalence of teleworking would affect both the residence location choice (for reduced overall commuting cost per week) and the mode choice (for likely increased flexibility in working hours). Nonetheless, there is no empirical data available for estimating the elasticity of household relocation with respect to the reduced weekly commuting cost. We thus do not consider the possible residence relocation and assume that in the teleworking scenario, all employed residents remain their original home location as in the baseline scenario. The scenario result is shown in Figure 14.

Figure 14 Scenario output: Potential reduction of commuting flow by all modes due to teleworking in Cambridge (based on the 2051 baseline scenario)



It shows that the possible impact on commuting is not evenly distributed across the study area. The teleworking may reduce the journeys to work both within the City and across city boundary. In particular, the commuting flow from Cambourne, Comberton, Northstowe and Impington to Cambridge may see a significant reduction. Two policy implications may be drawn from this preliminary impact study of teleworking on commuting. First, the fast growth of self-employed and part-time workers in the study area since 1981 suggests that flexible working arrangement such as teleworking may become prevalent in the study area. The possible impact on journeys to work could be significant in magnitude, which poses new challenges to transport demand forecast. Second, the prevalence of teleworking may bring radical changes in terms of the relationship between work and location. On the one hand, the emerging co-working space is blurring the boundary between jobs and workplace – teleworkers search for a suitable place to work and fill that workspace but not necessarily a job. On the other hand, planners, developers, architects and employers need to consider new models of providing and managing workspace (e.g. hotdesking), not simply reducing the floorspace per worker, but considering the flexibility and adaptability of space and the wider impacts on workers' productivity and welfare.

Some caveats should be noted. First, literature on tele-/remote working suggests that the reduction of commuting trips may result in the increase of non-commuting trips, and the total time budget for travelling in fact remains quite stable over time and among population[8]. Although teleworking may reduce the demand for commuting for certain types of jobs, the impact on overall travel demand is not clear. Second, digital technology is likely to be a key enabler for teleworking – it involves a wide range of technology, such as cloud platform, immersive technology and the underlying physical infrastructure such as fibre broadband, mobile connectivity. The teleworking scenario in this study does not consider the availability of such technology in specific locations.

Scenario 2: Electric vehicles charging demand

The design of this scenario is inspired by one particular finding from the workshops and interviews with local authorities - replacing the existing combustion-engine vehicles with electric vehicles (EVs) is deemed as the ultimate solution to air pollution as it addresses the root of the issue. However, the large-scale take up of EVs is subject to the capacity of local electricity grid, which is already under considerable strain (e.g. the Addenbrooke's hospital area). This scenario thus aims to address the interdependences between the environment, transport, land-use and energy system in local policy making.

This scenario assumes that all vehicles commuting to Cambridge including those commuting within Cambridge are EVs. To simplify the energy simulation, we do not differentiate the types of EVs and assume a uniform electricity consumption per km travelled by EVs (0.151 kWh per km; source: DfT-WebTAG, 2018, A1.3.8). The electricity charging demand for non-commuting use of EVs is also not considered. The key policy variable in this scenario is the spatial distribution of future housing and employment growth in the study region (see Figure 15). A total of three alternative spatial development strategies are tested, which are in line with the scenario setting in the CPIER report (see footnote 5 on page 9 for more information about the CPIER report). The digital twin model predicts how alternative spatial strategies may affect the distribution of EVs charging demand across the study region.

The prediction for the 2051 Baseline is presented in Figure 16. To highlight the possible impact of nudging people in terms of where to charge the EVs, we further assume that all commuting EVs can only be charged at either workplace or home place. The results for the Densification and the Fringe Growth are presented in Figure 17 and Figure 18 respectively.

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[8] Hägerstrand, T. (1970). What about people in regional science? Papers in Regional Science, 24(1), 6–21. Zahavi, Y. (1979). The UMOT Project. A report prepared for the US Department of Transportation, Research and Special Programs Administration, and the Federal Republic of Germany Ministry of Transport. DOT-RSA–DPW-20-79-3.

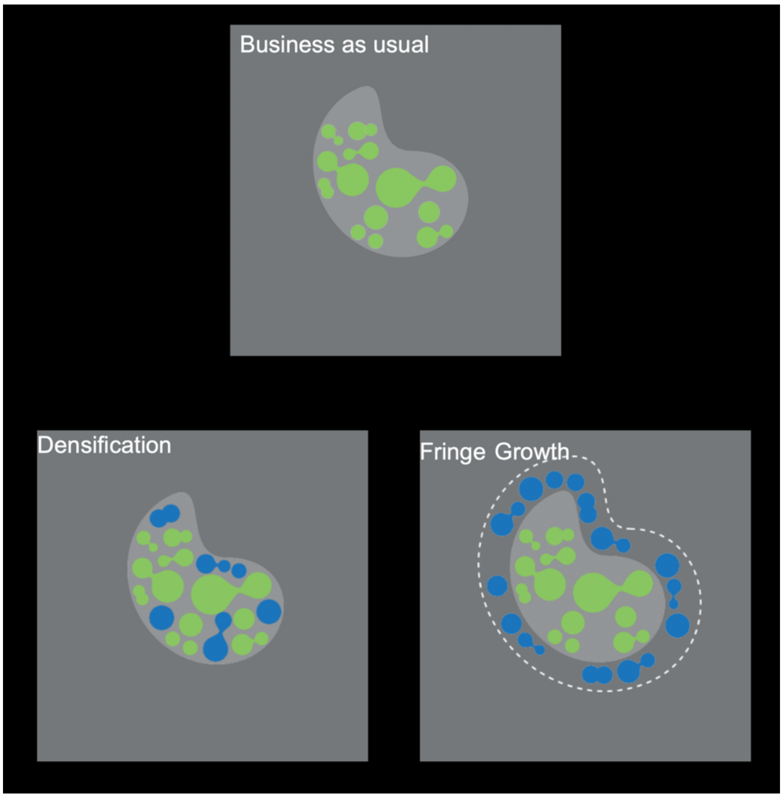


Figure 15 EVs charging scenario: Alternative spatial development strategies for Cambridge and the environs

<u>Business as usual (Baseline)</u>: extrapolation based on the historic growth pattern (1981-2011) for housing and employment

<u>Densification</u>: concentrating the majority of growth within the existing City boundary

<u>Fringe Growth</u>: Allowing the City to expand outwards on the fringe, which requires releasing some greenbelt land for development

Figure 16 EVs charging scenario: 2051 Baseline – 100% charging at workplace (Left) vs at home place (Right)

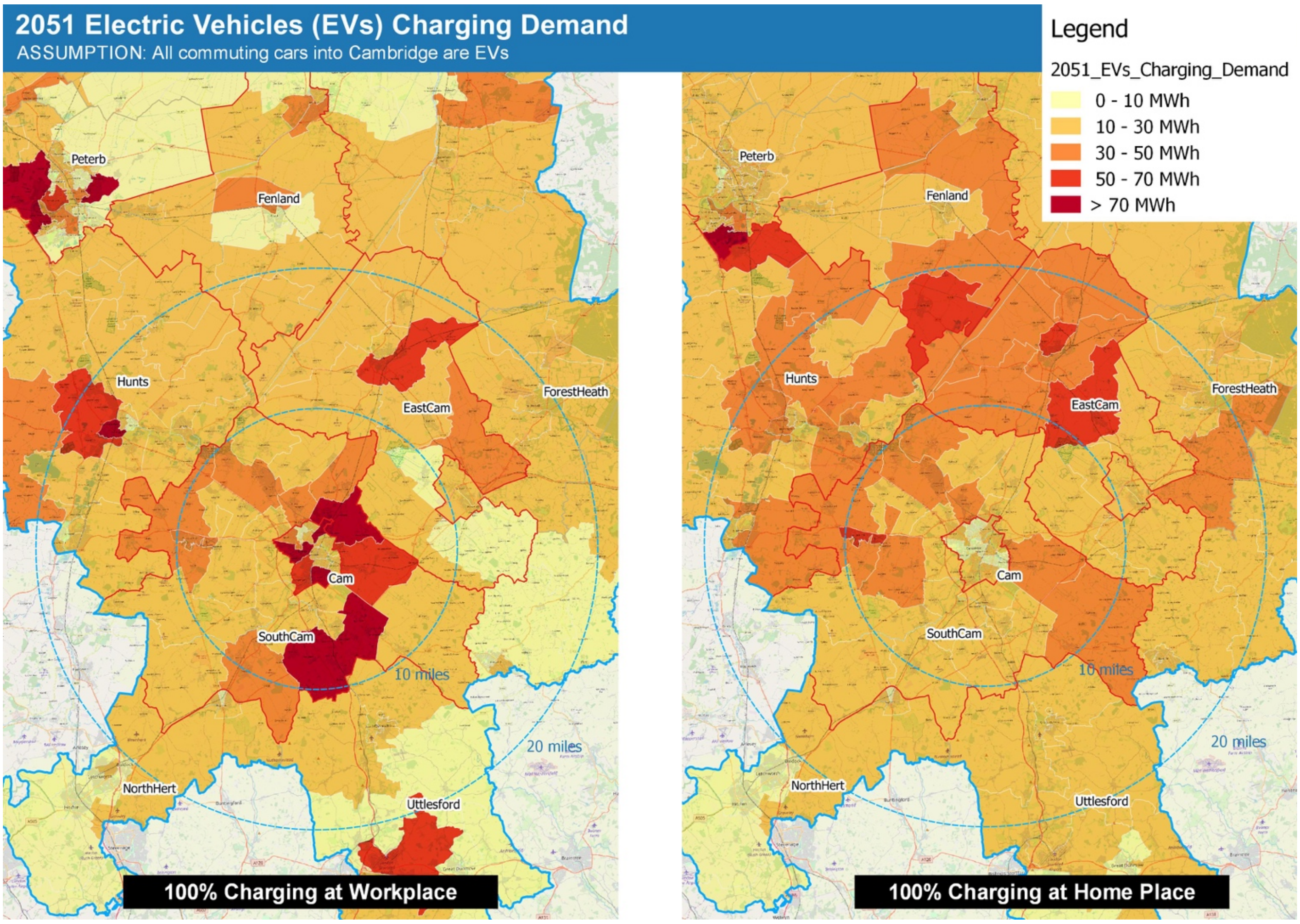


Figure 17 EVs charging scenario: 2051 Densification – 100% charging at workplace (Left) vs at home place (Right)

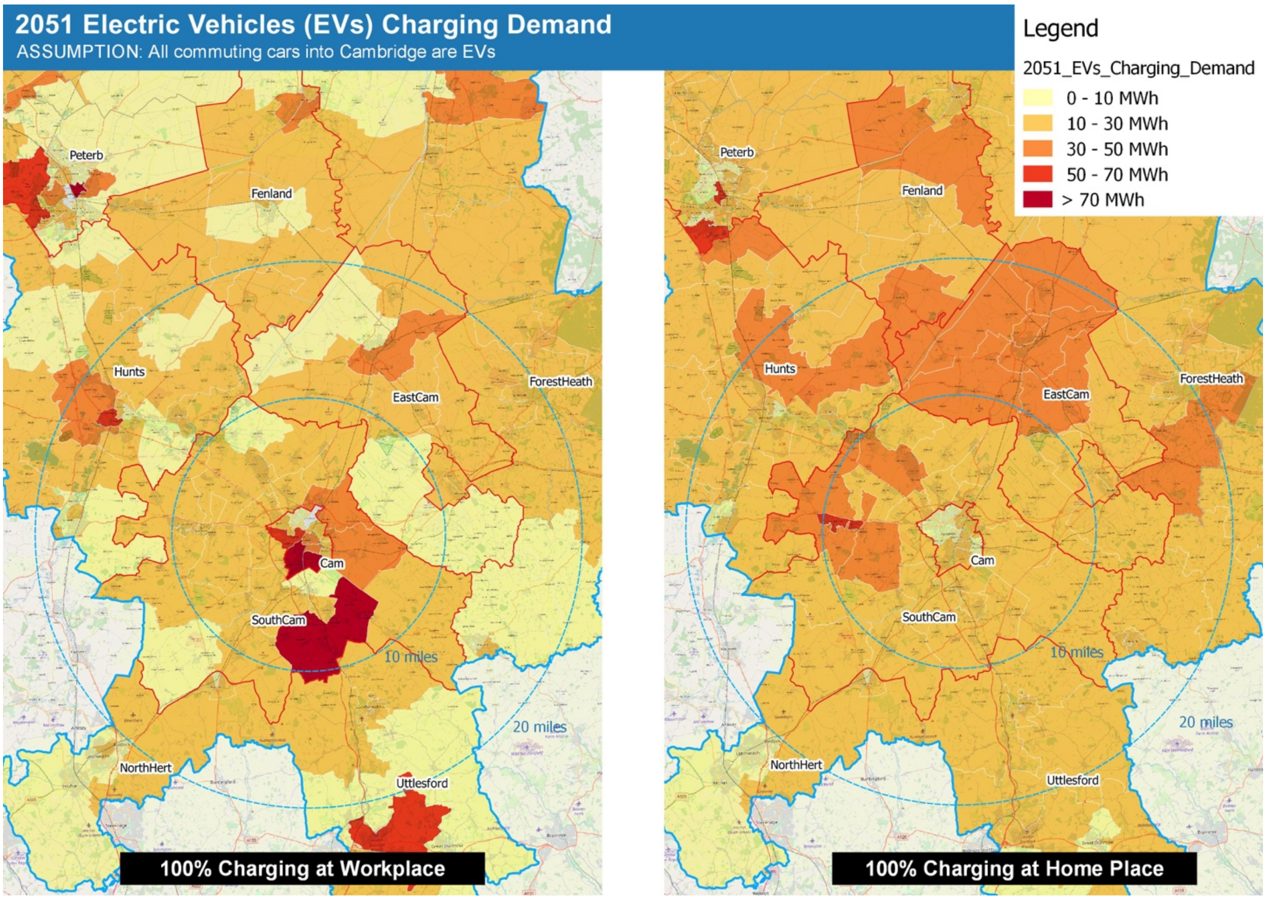
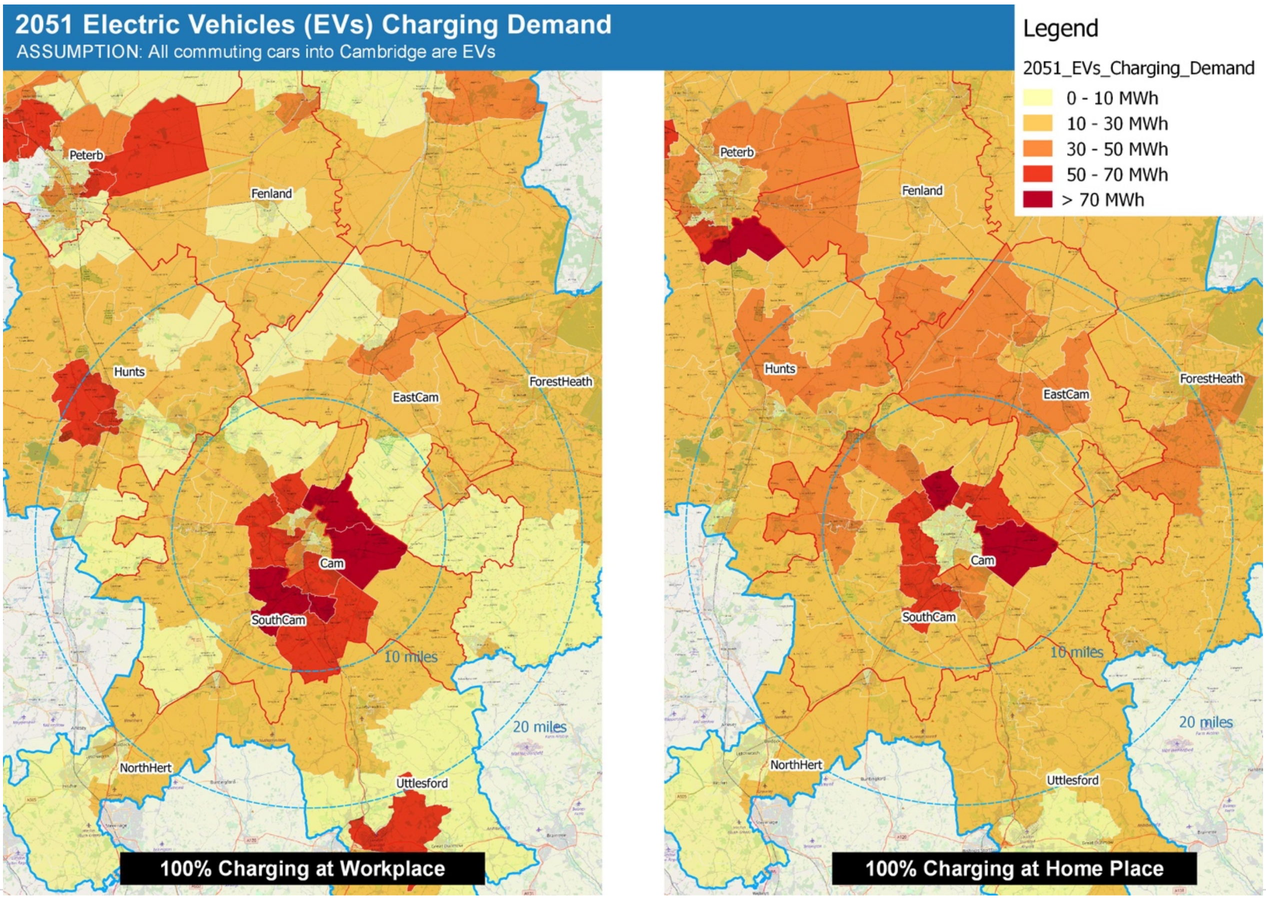


Figure 18 EVs charging scenario: 2051 Fringe Growth – 100% charging at workplace (Left) vs at home place (Right)



Policy implications of the EVs charging scenario are summarised as follows.

- A high level of spatial variance is observed in the distribution of charging demand for commuting EVs. The further concentration of employment in Cambridge (as in the Densification scenario) results in the highest charging demand in Cambridge if commuting EVs are all charged at workplace.
- Upgrading the energy infrastructure in the dense centre of Cambridge is likely to be expensive accompanied with severe disruption to local businesses. Nonetheless the increased electricity demand may be shifted away to other locations in the short term through pro-active pricing policy on charging and/or parking at workplace, as suggested by the comparison between 100% charging at workplace and home place in the figures. To make it possible, it requires better collaboration between transport, housing and energy team in local government.
- The feasibility of shirting EVs charging demand between workplace and home place is less in the Fringe Growth scenario, as more workers live in proximity to their workplace. The improved job-housing balance on the fringe also indicates a reduced average commuting distance compared with the Baseline.

It should be pointed out that the scenario results are rather crude due to the various simplifications in scenario design. The purpose of this scenario is thus not to provide an engineering solution for optimizing the distribution of future EVs charging demand, but to demonstrate the potential of city-level digital simulation tools for facilitating cross-boundary collaboration in policy making in local government.

4 Potential contributions to a Digital Built Britain

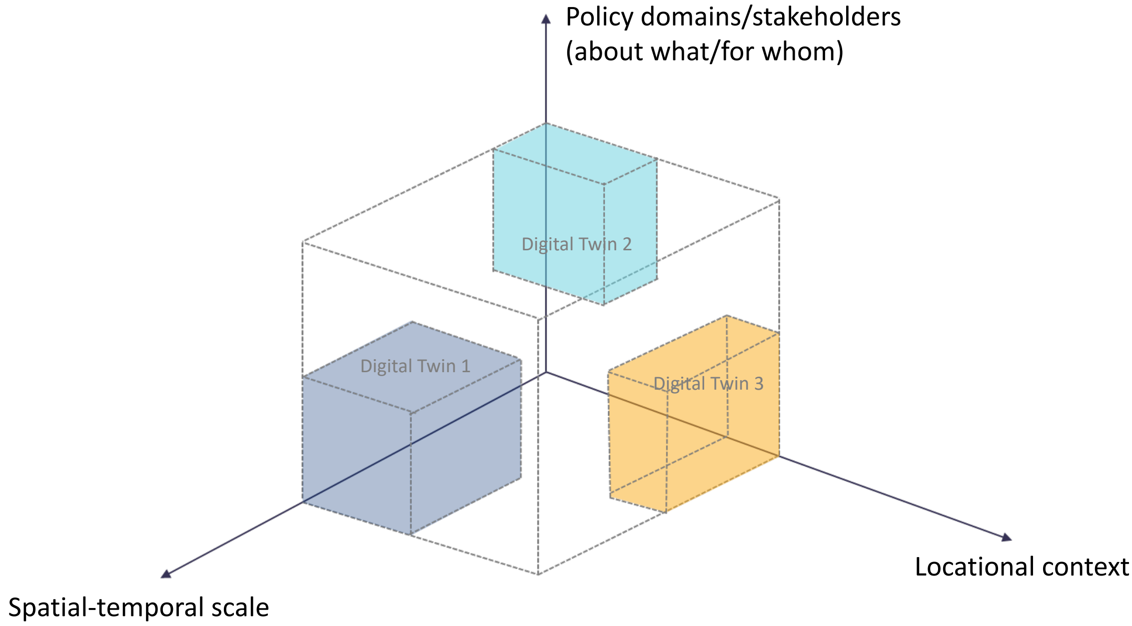
Inspired by the UK National Infrastructure Commission's recommendation for a national digital twin and the recent progress of the Digital Framework Task Group and Centre for Digital Built Britain, this short project explores the concept of a city-level digital twin in terms of the design, development and application through a modelling case study in Cambridge. In light of the Gemini Principles, this project also aims to test and verify the high-level principles in a real policy context, and generate transferable knowledge on city-level digital development.

In additional to the key research outputs discussed in the last section, we summarize a series of working propositions regarding the development of city-level digital twins, which are derived from the Cambridge digital twin exercise. An early version of these propositions has been presented on the 2019 International Conference on Smart Infrastructure and Construction (ICSIC) in Cambridge[9]. It is expected that these propositions will guide the future research and practice on city-level digital twin and thus contribute to a Digital Built Britain.

Proposition 1: The upscaling from an engineering digital twin to a city-level digital twin is not straightforward. For a city-level digital twin application to be useful and the associated discussion to be meaningful, key dimensions of the digital twin need to be articulated pertaining to the purpose, boundary, context and resolution of the specific digital twin as well as the interdependences among twin models. Three dimensions of such are proposed in Figure 19. 'Policy domains/stakeholders' denote the subject and representation of the digital twin (i.e. about what and for whom); 'locational context' includes the social, economic, political and geographic background; and 'spatial-temporal scale' indicates the resolution of the twin model.

[9] Wan et al. (2019). Developing a City-Level Digital Twin – Propositions and a Case Study. International Conference on Smart Infrastructure and Construction 2019 (ICSIC). January 2019, 187-194

Figure 19 Key dimensions for defining a city-level digital twin application



Proposition 2: Digital twin development is a progressive process; the digital twin and the social system that creates and uses it must co-evolve with each. This proposition relates to the intellectual relationship between the digital twin and the human society. On the one hand, our existing knowledge about cities and societies defines how well we could development and use a city-level digital twin. On the other hand, artificial intelligence (AI) may eventually become comparable to or even surpass human intelligence in terms of knowledge production and decision making. In the wake of recent data misuse and privacy breach incidents (e.g. the Cambridge Analytica case), the co-evolving proposition addresses the imperative for harnessing the power of AI through pre-emptive measures.

Proposition 3: Real time is a relative term. The temporal scale of the digital twin should reflect the rate of change of the subject in reality. The real-time feature as in engineering digital twin applications denotes the low latency in updating the twin model against the reality. The transition from a manufacturing product as the subject of a digital replica to a city entails the term 'real time' to be redefined. It contests to the simplistic pursuit of high-frequency data regardless of the purpose of the digital twin.

Proposition 4: To advance the city-level digital twin agenda, digital twin applications should be focused on enabling more frequent and effective feedback loop between the twin model, stakeholders and the public. One major problem of using urban computational models in policy making is the lack or inefficiency of feedback, which can manifest itself in various ways, e.g. model as a 'black box', no post-analysis validation and the detachment from public engagement. From a modelling perspective, the implication is that the interaction between the model and the users is far from perfect even for modelling experts. New interface thus needs to be explored which can translate data analytics into cogent narratives targeted to various stakeholders. To achieve it, modellers may have to think beyond models, which is apparently more than a technical request.

Proposition 5: To help solving complex policy challenges, a realistic use of a city-level digital twin is to identify system-level risks and inefficiencies of policy interventions and to foster cross-disciplinary/professional collaboration, as opposed to providing a singular model-based

optimization. System-level optimization, though being the explicit purpose of some digital twins in the engineering sphere, may not be an effective approach to address “wicked” urban problems. One of the reasons is that developers of the digital twin, given their technical background, often do not have enough understanding of the non-technical factors (e.g. election cycles, hierarchies of decision making, institutional constraints). These non-technical factors are usually highly influential but tend to be very difficult to be incorporated in the model. A model-based optimization which does not consider such non-technical constraints would have little meaning.

It should be noted that these propositions are neither conclusive nor exhaustive. It is expected that the propositions could be further tested and expanded through more empirical research.

Conclusions

The digital twin technology represents one of the latest technical trends for smartening our cities. However the roadmap to develop a city-/national-level digital twin is not yet clear. This project represents a timely effort to explore a policy-oriented strategy for developing a city-level digital twin prototype for the Cambridge sub-region. Key research outputs are discussed and a series of propositions are proposed for guiding the future research on city-level digital twin.

The project is nothing but a small step towards the ambition of creating a national digital twin for the UK infrastructure. It is expected that more and more empirical evidence will be gathered to establish a new body of knowledge for leveraging and regulating the power of digital twins. As discussed in one of the propositions, the development of a digital twin is a progressive process, where the digital twin and the social system that creates and uses it must co-evolve with each. Much remains to be done.

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References

Please refer to the footnotes in the text.