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Smart Data-Harnessing for Financial Value in Short-Term Hire Electric Car Schemes

Peter Cooper
Faculty of Engineering
University of Bristol
Bristol, UK
Email: peter.cooper@bristol.ac.uk

Tom Crick
Department of Computing
Cardiff Metropolitan University
Cardiff, UK
Email: tcrick@cardiffmet.ac.uk

Theo Tryfonas
Faculty of Engineering
University of Bristol
Bristol, UK
Email: theo.tryfonas@bristol.ac.uk

***Abstract*—In the developed world, two distinct trends are emerging to shake-up the current dominance of privately-owned, combustion motor car transport. The first is the emergence of the electric powertrain for vehicles as an affordable and mass-marketed means of transport. This carries with it the potential to address many of the immediate shortcomings of the current paradigm, especially CO2 emissions, air and noise pollution. The second is the rise of new hire models of car ownership – the concept of paying for the use of a car as and when you need it. This carries with it the potential to address many of the existing issues: outlay-induced car use, residential parking and social division. On a similar timescale, we are witnessing the rise of smart technologies and smart cities, concepts that use data about the state of a system or elements of it to create value.**

There have been relatively few examples of schemes that have combined the electric and hire-model concepts, despite the huge potential for synergy. Indeed, the majority is against them on both counts – cars are predominantly privately-owned and driven by internal combustion engines. Nevertheless, there is significant potential for this to change over the coming years.

***Keywords*—Electric Vehicles, Vehicle Hire Models, Smart Technologies, Smart Monitoring, Smart Cities, Big Data, Environmental Impact**

I. Introduction

The last decade has demonstrated the current Western private transport paradigm has a finite lifespan; a transport culture that consists of overwhelmingly privately-owned internal combustion engine automobiles is unlikely to survive the next 50 years.

Two distinct cultural trends are bringing about its demise. Most notably is the emergence of electrical motors as the primary alternate fuel source in powertrains for automobiles. Almost all of the world's major automotive companies have released purpose-designed electric cars; some have had made strategic investment in the concept as to release an entire electric car range, underpinned by efficient driving technologies, for example BMW's i Series and EfficientDynamics system[1]. The direct environmental benefits of electric cars, lower particulate emissions, lower noise emissions and the potential for lower CO2 emissions, are highly significant. Legislation in many countries is acting in two ways: penalising internal combustion engine users, and incentivising the purchase of EVs. Electric cars bring with them several caveats, however: the capital cost of EVs, predominantly due to current battery technology, is yet to be comparable to an equivalent internal combustion engine car; the embodied carbon of EVs, again due to the battery component, is on average considerably higher than an equivalent internal combustion engine, and the generation of electricity to meet charging patterns brings with it considerable logistical difficulties.

More in its infancy is the trend of transitions in car use models. In other modes of private transport, predominantly bike use, an increasing number of users are opting to participate in short term hire models of use, particularly in urban contexts. Rather than baring the capital and logistical cost of owning a bike, individuals hire the bike for a nominal fee from a given node near their origin, complete their journey, and return the bike to a node near their destination. Once seen as radical, examples such as London's cycle hire ("Boris Bike") scheme[2] demonstrated not only the feasibility of the business model, but also the efficacy of the indirect benefits, illustrated by significant increase in cycling in the city.

A third, more generalised trend in societal organisation is the emergence of the smart city theorem. This capitalises on the use of 'smart technologies', systems that harness opportunities data presents to provide value; in the smart city theorem this cuts across city system boundaries. In other words, the data from one particular aspect, such as waste disposal, not only informs the operation of waste disposal, but also, for example, influences how the road system operates during waste collection hours.

However, transition is, at present, slow. Electric cars only make up a negligible share of the UK car market (with limited infrastructure outside of major urban areas), short-term hire transport models have yet to be proved beyond simpler transport situations, such as bicycles, and smart cities are, in many cases, little more than a long term strategic aspiration, with some instances of demonstrators, most of which are too early in their lifetime to be able to provide any real conclusions.

The actions of policy makers in the next 10 years will dictate how much these trends are harnessed, encouraged or ignored, and ultimately how the UK's transport culture changes as a result.

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[1] http://www.bmw.co.uk/en_GB/topics/discover-bmw/efficientdynamics/technologies.html

[2] http://www.tfl.gov.uk/modes/cycling/barclays-cycle-hire

II. UK Policy Context

Politically, the UK's transport strategy lacks resolve and strategic planning. A heavily departmentalised, part-privatised transport system lacks consistent objectives, agendas or priorities. Multimodal travel design is attempted coarsely, with new transport systems being overlaid on the old, with little foresight or retrospective adjustment.

Over the last 60 years, transport journey makeup has transitioned rapidly from public transport-dominated to a private transport-dominated network, stabilising at the end of the 2010 decade. Vocal, anti-automotive political agendas, global recession and rising oil prices have all emerged since as powerful, anti-private transport influences. However, they have done little to reduce private transport, with transport behaviours appear largely unchanged, tending instead to a marginally lower equilibrium level today. This is displayed in Figure 1, contextualised by the historical car ownership trends (cars per person in the UK): 0.004 (1909), 0.08 (1950) and 0.55 (2012).

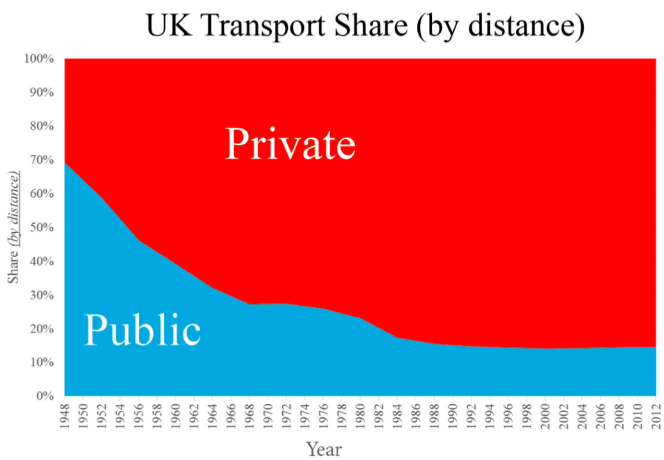

Figure 1. Car ownership trends in the UK

In theory, it is clear that public transport is both technically (in terms of emissions per head) and systematically (second-order effects, such as congestion, social and economic consequences) superior to private transport. However, it is equally apparent that the unit cost of converting a percentage of transport users from private to public transport increases with conversion. For example, to convert the easiest first 10% of users, a network of urban buses and trains can be run cost-effectively and efficiently. The last 10% of the population, however, requires a vast and complex network that operates constantly and at high frequencies, and is for all intents and purposes, impossible to deliver. As such, it is clear that there is a fraction of transport that, for reasons of financial and practical limitations, will always remain private transport, and that that fraction is not necessarily 'small'. Although the UK does not currently operate at or even near this 'minimum' private transport threshold, acknowledgement that any such unavoidable level exists is not popular politically.

As such, in private transport, there is an idea that any impacts, both technically and systematically, should be mitigated. This is a popular and high-growth area of research; within the last 20 years, personal automobile efficiency has improved drastically. Today, alternate powertrains such as electric motors, more efficient and less polluting that internal combustion engines, are not only technically viable, but a key component of many automotive giants strategies; the aforementioned BMW i Series range is a high profile example of significant strategic investment in the transition of retail automobiles to EVs. However, it is clear that drivetrain transitions alone cannot deal with the systematic drawbacks of private transport, such as congestion, special requirements of parking and social isolation of the have-cars and have-nots. Technological suggestions for these problems do exist, such as driverless, automated cars and personal rapid transit (PRT) schemes, but both are a long way from a ready-to-rollout status. Crucially, for every change that improves the negative impact of private transport, or more accurately, convincingly depicts itself as doing so, private transport is further legitimised, and efforts to transfer journeys to public transport are weakened.

Political action is thus limited by this simple catch-22: public transport is the ideal, but impractical to reach saturation. Private transport is undesirable, but unavoidable, yet efforts to improve it also make it more prevalent. Mathematically, you might argue there thus exists an optimum – a level of improvement of private transport that, when the reduction in public transport uptake is factored in, results in the lowest overall impact in the UK's travel emissions. Whether or not this thought experiment is a fair simplification, there is a more logical and pragmatic answer – that transport strategy should be considered on a holistic level, and the interaction between private and public transport held as crucial. There are many more secondary effects that could also be considered from this first deduction; not all improvements to private transport reduce public transport uptake to the same degree; nor is the UK a homogenous mass of two types of transport user. Attempts to penalise private transporters who could transfer to public transport and do not, such as through taxation, frequently damages those who cannot transfer.

Ignorance to these wider socio-cultural relationships, brought about by the private/public segmentation of both traditional transport strategies and the segmentation of organisations tasked with dealing with each, allows these undesirable, unintended consequences to continue and prevent technological and political progress.

A. *Electric Vehicles*

Electric vehicles (EVs) can offer an environmentally sustainable alternative to internal combustion engines (ICEs). EVs are powered by a battery which is charged through the electricity network. Alongside reducing carbon emissions, EVs can also improve noise and air quality, provide savings for consumers and reduce dependency on specific fossil fuels [1]. It is widely accepted that an alternate energy source is necessary for the UK transport network in the near future, and electrification is currently considered the most likely choice. The Department for Transport (DfT) predicts that by 2020 there will be 1.5m EVs on the road in the UK [2].

There are a number of barriers to the adoption of EVs. Many of these are psychological, for example range anxiety; consumers worry that they may 'run out of juice' [3]. However, 95% of all vehicle journeys in the UK are less than 25 miles (40km) [3], only a small proportion of existing EV's range. Other consumer barriers include: concerns over battery lifetimes, the risk associated with investing in a relatively new technology and the current, comparatively large capital investment required to purchase an EV.

Personal vehicles and small commercial vehicles account for 13% of all UK carbon emissions [4]; by transitioning to EVs in these sectors, the overall volume of emissions could be significantly reduced. Due to the nature of UK car culture, fleet vehicles accounted for 63% of all new vehicle sales in the UK in 2011 and as such are a dominant influence on the type of cars for sale in the used market [5]. There is a growing trend for EVs in fleet vehicles, so it is likely a tangible used EV market will start to emerge in the next five years.

Electrified public transport is still a fairly new area of interest. Hybrid buses have been introduced in a number of cities to reduce emissions, with London having 368 hybrid diesel-electric buses in operation in 2014 [6]. In January 2014, the first inductive charging all-electric buses were introduced into service in Milton Keynes[3]. The UK Government is supporting investment in low carbon bus technology through the Green Bus Fund[4], as well as many other general, sustainability-targeted funding packages.

B. Smart Technologies

Smart technology is a new and rapidly growing concept; as such, a consensus of its exact definition has yet to be reached. However, interviewed academics [7], industrial experts [8] and a number of papers [9]–[12] identify the fundamental, unifying theme as the use of data. The rise of interest in data-based possibilities for the built environment has been fuelled by three key developments:

1) **The rapid increase in the production of data.** Computer scientists have stated that many social trends, such as the rise of Internet connectivity (specifically high-speed mobile Internet), and social networking, has caused an exponential increase in the production of data. Today, almost 30 petabytes of data exists on Facebook alone[5]. The abundance of such a resource has spurred consideration as to its potential use.
2) **The rapid increase in the ability to collect specific data.** Improvements in sensor and communication technology have meant the installation of data collection devices is now both financially and spatially practical. The development of mesh networks, the notion of deploying equally spaced sensors across a large area to give a high resolution of data or the ability to track the movement of entities. Furthermore, the Internet of Things, the notion that with the deployment of connected sensors on existing everyday objects, interactions that are currently machine-human-machine could simply be machine-machine, allowing many such processes to be faster, cheaper and more convenient.
3) **Improvements in data storage and processing.** Following Moores Law/Kryder's Law, storage is far cheaper than ever before, allowing this vast data to be stored. Processing power is also much greater, allowing complex trends from data on scales so vast as a city to be processed and actioned fast enough to be considered 'live'.

Many such sources refer to data as a raw material (perhaps even an emerging 'utility', joining electricity, gas, water and telephone networks), creating the notion that data can and should be used as an input to a business model that is then translated to value. In recent years the practicalities of collecting and processing a vast quantity of high value data of a system, as discussed, has developed significantly [10]. Such a system could be a house, business or city, with data being the movement of containers in a factory, the journeys of cars across an urban network, or the use of electricity residentially. The sheer volume of data available for such a large range of systems has led to the term 'big data, now commonly used to refer to a datastream large enough to make smart technologies feasible [13]–[15].

Smart technologies are usually defined as microsystems within these larger systems that carry out an action based on the collected data. Smart technologies are typically based on an existing action that, it is theorised, could be completed more effectively – as well as sustainably [16] – with the assistance of data [10]. More effectively can be interpreted as:

- **Faster:** such as using traffic distribution to update signs in real time, rather than the slow, reactive methods by which traffic is informally advised against taking certain routes.
- **Fairer:** such as smart pricing for grid electricity, whereby data on the national grid is used to charge those who use electricity when demand is highest (when the cost of generation is highest), a cost that is reflective of the cost to supply the electricity to them.
- **At lower cost:** whereby flow sensors in water pipes can be used to deduce the exact location of leaks when they emerge, rather than expensive and time-consuming visual inspections.
- **Without human interaction:** whereby more interactions can be machine-machine rather than using a human intermediary, such as when an inspection robot is automatically sent to the site of a machine malfunction in a factory, rather than a human noticing the fault and piloting the robot manually. This can improve instances of both human error, hesitation and subjective judgment (for better or for worse).

Smart cities are urban areas in which smart technologies are taken a step further, and different city sub-systems such as waste disposal and water provision are integrated. In practice, this results in smart technologies using data streams from neighbouring systems [17]. For example, in a theoretical world where there is near saturation of EVs, preemptive car journey data could be used to adjust the national grid's generation so as to ensure the correct amount of power is generated for the EVs recharging at the time they are expected home. Such intelligence allows for more efficient generation, avoiding the short-notice generation that is currently employed [18].

III. The Role of Smart Technology

A. Approach

We will now consider the role of smart technology within the futures transport strategy, specifically integrated

[3] http://m.bbc.co.uk/news/technology-25621426

[4] https://www.gov.uk/government/publications/details-of-the-green-bus-fund

[5] http://www.theguardian.com/news/datablog/2014/feb/04/facebook-in-numbers-statistics

private/public and electric transport solutions for a range of suggested concepts in existing literature covering smart technologies of a number of different industries, we will consider the nature and operation of each in the wider smart transport context.

For the purposes of this study we will consider the benefits of these smart technologies specifically from a private sector business case viewpoint; that is to say, primarily the financial and economic benefit they could bring (although they also have significant social, political and environmental benefits).

B. Cars

Standard car hire industry practice is to operate a maintenance regime that involves inspection above the recommended frequency, designed to reduce the time between inspections when the car may suffer from a freak failure. Freak failures are defined as those whereby there was no indication at the last inspection that the car would fail before the next testing.

Using health and usage monitoring sensors attached to key components in the car, the car hire operators can get an understanding of level of car mechanical state close to that offered by an inspection, but constantly and in real time. This could drastically reduce the rate of freak failures and, if the sensor coverage was sufficient enough, potentially allow reductions in human servicing. This concept is already well understood in industrial contexts and frequently realised. The value from this system comes from improved reliability and efficiency of the car hire service.

C. Live Air Quality Management

Bristol (a major city in the west of England) monitors air quality by semi-permanent installations at specific areas around the city. In a typical UK urban environment, particularly one with no major industry, air quality is primarily determined by road transport emissions. As such, if it was possible to understand the overall distribution of vehicles in the city at any one point in time, it would be possible to estimate, with relative accuracy, the air quality throughout the entire city. At present, in some areas of the city, car flow is monitored by car-recognising cameras. These however are sparse and expensive to install.

The car hire EVs are likely to use the same roads to the same intensity of other cars on the road at that time. In other words, their road routing behaviour is likely to be very similar, if not identical, to the rest of the cars on the road at that time. As such, a critical resolution of hire cars is necessary to deduce an estimate of the wider car resolution. We will examine critical resolutions in detail at the end of this section. The value from this system comes from the created market of vending car locational data to Bristol City Council.

D. Live Accident Reporting

Similar to in-car monitoring for maintenance, vehicles can also be fitted with impact sensors, altering the car hire management that a car has suffered a serious crash, allowing them to contact the authorities. Due to the significant improvement in road safety regulations, mobile phones have already improved road transport since the mid-2000s, and the relative rarity of isolated crashes, it is unlikely the value case here can be made from a practical improvement in fatality rates from car hire use.

Instead, it is probable that the main benefit of such a system would be perceptual improved piece of mind for the customer that a system will be in place to constantly evaluate their safety. However, the increase in service from such a technology yields a relatively insignificant revenue stream.

E. User Journey Data

One of the fastest growing applications of data is within retail and leisure industries. Many organisations using big data have shown that advertisement conversion rates (the percentage of individuals who act on an advertisement they have seen) can be greatly increased by accurate targeting of the advert to the correct recipient. Traditionally, this would be done by geographical area or age group. More recently however, with the ability to better express to the world your other preferences and personal situation through social media networks, it is possible to advertise to people of a specific relationship status, group affiliation or fans of similar services. Facebook and Spotify are prime examples of how specific demographic, geographic and chronological conditions are set to not only able to return high conversion rates, and thus, expensive advertising to customers, but also, as a result, able to vend smaller advertising exposures as a tangible product. This means a greater number of clients, and thus a more robust business model.

In the car hire, two potential avenues of value creation are possible. Firstly, information on the journeys of car hire individuals alongside the time they drive and their personal characteristics, could be vended in a data package to companies in retail and leisure industries. These companies would have otherwise had to undertake expensive customer research, thus the value is clear. However, this is very likely to suffer from extremely low consent rates, as it would perhaps be the most invasive form of personal data harvesting currently in existence. Alternatively, consent rates may well be much higher if the data was instead used to form targeted advertising at point of booking. This way, organisations could offer discounts to individuals it feels it may be able to convert to using their business on the trip, incentivising them to consent to the scheme. Furthermore, this could be done dynamically through the common advanced display systems that are available in modern automobiles. The revenue stream here will be two fold: the advertising organisations will pay for the in-car advertising rights, and individuals would be more inclined to travel through the hire car if special offers would be available. The primary value from this system comes from the vending of targeted, data-based advertising of in-car and pre-booking advertisement to local businesses.

F. Smart Pricing Congestion Control

An alternate method to control congestion is to bring economic forces to bare on when an individual chooses to travel. In practice, the car hire smart pricing would include an additional influence based on the expected congestion of the roads at point of travel, attempting to deter travel that would exacerbate the congestion. Ultimately, this requires the highest critical resolution of hire cars of all the smart technologies addressed here, by some margin, perhaps at least 25%. Furthermore, many ethical dilemmas exist. If the resolution is lower than 50%, it might be extremely unpopular that the most sustainable cars are essentially 'taxed' into staying off the roads, while the unsustainable private transport is free to do as it wishes. Although such a pricing technique would not be unlike current train pricing structures, the freedom to use a car when one desires is heavily ingrained in Western society, and it's likely any such pricing on that logic would need to be mild.

G. Charging Habits

Similar to the understanding of how individuals operate electric cars, the UK's National Grid[6] would be interested in how individuals charge their EVs, as this will heavily influence how the grid develops in the next 50 years. Although typically our EV's have predetermined charging patterns, EVs that are taken on multi-day rentals will most likely require charging to address the specific needs of the hirer. This provides a valid insight into the charging habits of EV users. The value from this system comes from the created market of vending charging habits to the UK's National Grid.

H. Car Positional Data

One of the issues with an electric car hire scheme, as discussed previously, is the increased layover time incurred by charging. This has been shown to be manageable in its standard incarnation, but certain instances could exacerbate this weakness, or simply be a problem for car hire management schemes in general. For example the following situations within a booking could threaten the ability to service later bookings:

1) **Inclement driving conditions:** EVs are susceptible to have sizeable variation of energy use per mile depending on driving conditions. Cold weather can have negative effects on electric torque. Additionally, heaters in EVs are unable to use the waste heat that a combustion car generates, so additional power from the battery is required; as much as 15% in certain circumstances [1]. Live battery data can allow the car hire management system to know the exact power use of a journey.
2) **Congestion:** Traffic can significantly decrease the efficiency of the EV; although the effect is lessened when compared to a combustion car as EV engine can turn off and on seamlessly. More significantly, congestion greatly increases the journey time. Car speed data and GPS location data can inform the booking management system when a car is stuck in traffic.
3) **Satellite navigation:** If an individual decides to take a longer route home, or even a route of the same duration of time but a greater use of charge (such as a longer motorway route compared to a slower trunk route). Live satellite navigation data can inform the booking management system the minute the drive has this intention.

Pre-warning of any of these unforeseen circumstances can allow immediate shifting of the booking system to reflect increased hire duration or increased charging duration. This will prevent people booking in a time when the car will now be driving/charging. The value from this system comes from improved reliability of the car hire service.

I. Barriers and Enablers

Each of these data streams and their associated benefits require capital and operational expenditure to put in place the infrastructure and staff that would facilitate the systems. Even without estimating this, it can be seen that a number of technologies are immediately unable to be financially viable, at least in isolation. Needless to say, this theoretical value is not instantly realisable. Considerable barriers exist to not only the creation of the value, but also the smart technologies themselves. At present legislation in the UK around renewables and EVs is under general scrutiny and review. Feed-in Tariffs (FITs) and other payouts for balancing services are complicated and have questionable longevity and there is little governmental impetus in the UK for smart pricing on a balancing level. Considerable psychological inertia also exists in some businesses as to the idea of data as a source of value. The issue of critical resolution is also present – Figure 2 demonstrates varying accuracy from predicting traffic levels at different sensor penetration.

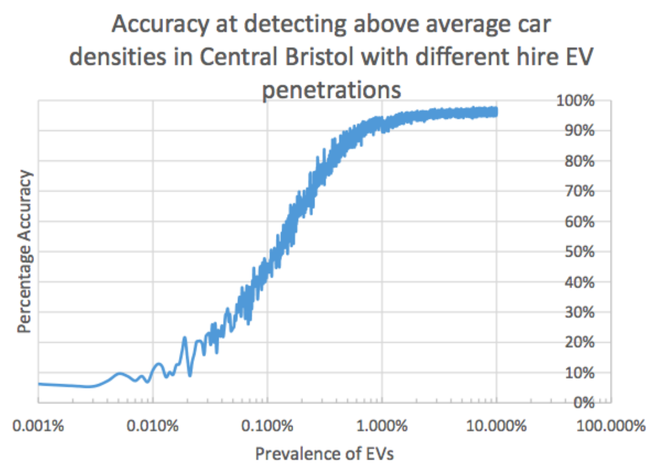

Figure 2. MATLAB modelling of the accuracy of extrapolating to find congestion from EV cars in Bristol, UK

IV. Conclusions

It is clear there is great variation in the nature and quantity of value in smart technologies with short term EV hire. These are presented in Figure 3. As a general rule, there are three categories:

- Firstly, those that have the greatest benefit but are also the most speculative, having the highest critical masses and requiring the greatest stakeholder buy-in. However, their benefit is extreme. These also have the highest quantity of non-financial benefit, typically environmental, which is often equivalent to, or in some cases higher, than the economic and financial benefits. These are typified by the smart pricing congestion control and the dynamic traffic routing. Although there is little probability that this group will be implemented in the near future, the significant potential cannot be ignored, and would serve well as a long

[6]http://www.nationalgrid.com/uk/

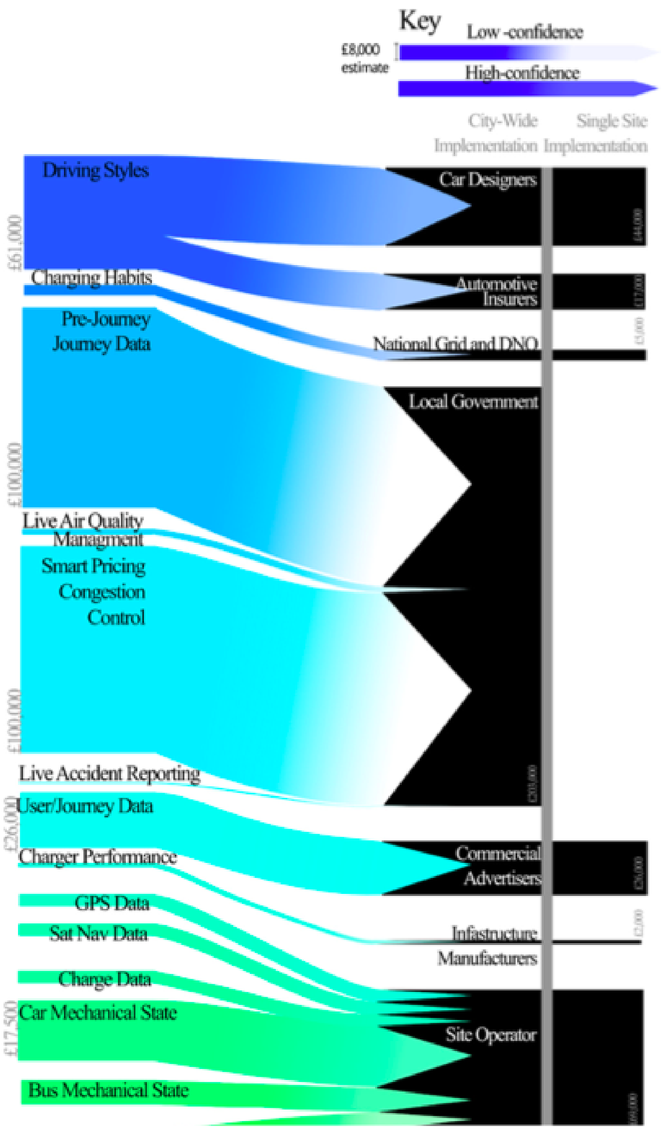

Figure 3. A Sankey diagram of the data value and confidence, along with single site vs. multisite implementations

term agenda for local council, be it with implementation through a smart transport hub or elsewhere.

- Secondly, a middle group, with moderate benefit whose speculation is somewhat less, but typically relies on a small, niche market for vending, and as such hinges significantly on this for any value at all. Driving styles is a typical examples of this. While there is some variation in the group – spin off elements such as the journey data, advertising approach fairs much better – it is difficult to label these as a quality. How UK law changes with respect to data use, as well as how contract culture changes with respect to data transactions will have a great influence. Many local governments or devolved city regions, including Bristol, are aspiring to wider open data initiatives, a system where similar data sets are freely available (and reusable), and the data is realised through the new businesses that open as a result. This stands, at least in some lights, in contrast to this category's technologies.
- Thirdly, and bucking the trend, is a group with moderate benefit, but whose speculation is low and requires only internal participation. This third group, typified by the smart pricing and car component monitoring, stand out as having the greatest appeal.

Ultimately, there is considerable potential for smart technologies to transform not only the profitability of short term EV hire schemes, but the wider societal benefit of the concept. Which of the above segments are most appropriate to focus on will depend on the exact context and buy-in from external stakeholders. It is equally apparent, however, that the world has some considerable catching up to do – socio-culturally, legislatively and psychologically – if any of these concepts are to be easily implemented, let alone the concept of the short-term EV and its benefits thriving across the globe.

References

[1] UK Parliamentary Office of Science and Technology, "Electric Vehicles," Tech. Rep. Report 365, October 2010.

[2] UK Department for Transport, "Investigation into the scope for the transport sector to switch to electric vehicles and plug-in hybrid vehicles," Tech. Rep., October 2008.

[3] Office for Low Emission Vehicles, "Making the connection: the plug-in vehicle infrastructure strategy," UK Government, Tech. Rep., June 2011.

[4] M. Lumsden, *Successfully Implementing a Plug-in Electric Vehicle Infrastructure*. IET Press, 2012.

[5] Transport for London, The Climate Group, Cenex, Energy Saving Trust, and TNT, "Plugged-in Fleets: A guide to deploying electric vehicles in fleets," Tech. Rep., February 2012.

[6] Transport for London, "Hybrid buses," Tech. Rep., September 2009.

[7] The Electric Generation, "The Future of EV Charging: Its about Standardization," http://theelectricgeneration.org/news_articles/the-future-of-ev-charging-its-about-standardization, May 2013.

[8] V. Buscher, February 2014, Director – Arup, Interview.

[9] N. Komninos, *Intelligent Cities: Innovation, Knowledge Systems and Digital Spaces*. Routledge, 2002.

[10] Arup, The Climate Group, Accenture and Horizon, University of Nottingham, "Information Marketplaces: The New Economics of Cities," Tech. Rep., November 2011.

[11] C. Harrison and I. Abbott Donnelly, "A Theory of Smart Cities," in *Proceedings of the 55th Annual Meeting of the International Society for the Systems Sciences (ISSS)*, 2011, pp. 7–22.

[12] M. Batty, K. Axhausen, F. Giannotti, A. Pozdnoukhov, A. Bazzani, M. Wachowicz, G. Ouzounis, and Y. Portugali, "Smart cities of the future," *The European Physical Journal Special Topics*, vol. 214, no. 1, pp. 481–518, 2012.

[13] R. G. Hollands, "Will the real smart city please stand up? intelligent, progressive or entrepreneurial?" *City*, vol. 12, no. 3, pp. 303–320, 2008.

[14] S. Dirks and M. Keeling, "A vision of smarter cities: How cities can lead the way into a prosperous and sustainable future ," IBM, Tech. Rep., December 2009.

[15] N. Villa and S. Mitchell, "Connecting Cities: Achieving Sustainability Through Innovation," Cisco, Tech. Rep., October 2010.

[16] E. Cosgrave, T. Tryfonas, and T. Crick, "The Smart City from a Public Value Perspective," in *2nd International Conference on ICT for Sustainability (ICT4S 2014)*, 2014.

[17] J. M. Shapiro, "Smart Cities: Quality of Life, Productivity, and the Growth Effects of Human Capital," *The Review of Economics and Statistics*, vol. 88, no. 2, pp. 324–335, 2006.

[18] L. Tsoukalas, "From smart grids to an energy internet: Assumptions, architectures and requirements," in *Proceedings of the 3rd International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT 2008)*. IEEE Press, 2008.