Digitally-Enabled Electric Vehicles As-a-Service: Exploring the 'Tri-Opt' of Novel Private Transport Business Models

Abstract

Three distinct trends have emerged that have disrupted the dominance of privately-owned, combustion car transport in the UK. First, the emergence of the electric powertrain as an affordable means of transport, with the potential to address many pump-to-tire shortcomings, especially CO_2 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 per single leg of a journey, addressing systematic impacts such as residential parking, purchase-justifying-use and social division. Thirdly, the rise of 'smart city thinking', the concept that increased connectivity and data availability can be harnessed to create value, specifically here as it impacts transport. We define the combination of the three as the 'Tri-Opt' of private transport – three disruptors that should not be considered in isolation but as interacting levers – an inflection of the 'Energy Trilemma'.

In this paper, we apply systems thinking and a mixed methodology of workshops, interviews and systems modelling drawing upon the UK city of Bristol's Smart EV Transport Hub project to identify concepts that positively combine two or more of these three 'Opts'. Subsequently, the use cases are evaluated qualitatively for their broad perception of value and potential. Segmentation is subsequently undertaken to characterise and generalise groups of concepts to inform recommended stakeholder actions. We demonstrate that synergistic overlaps are many and combinations create significant value. Our data highlights that of the greatest value are those use cases that the current literature base has explored the least, and can be characterised as requiring significant public and private sector collaboration. We thus highly recommended that public-private sector collaboration in private transport – particularly on the issues of electric vehicles, smart cities and mobility-as-a-service – is prioritised for further research and investigation.

Keywords: *Electric Vehicles, Vehicle Hire Models, Smart Monitoring, Smart Cities, Environmental Impact, Business Models, Mobility-as-a-Service*

1 Introduction

1.1 Problem Space

A growing corpus of research – as well as associated policy declarations – is gathering consensus on the view that the prevailing private transport paradigm of developed nations has a finite lifespan; a culture that consists of primarily privately-owned internal combustion engine (ICE) automobiles is unlikely to survive the next thirty years in its current form, in the face of economic, social, and environmental pressures (Black et al., 2016; Lerner, 2011; Van Audenhove et al., 2014). Several distinct trends in existing research have emerged as potential disruptors; three in particular are identified and analysed in this paper. Firstly, the emergence of electrical motors as the primary alternate powertrain for private automobiles (Gnann et al., 2015; Paffumi et al., 2015). Secondly – and more in its infancy – the trend of transitions to new car use models, which is regularly referred to within the collective term of 'Mobility-as-a-Service' (Transport Systems Catapult, 2016). A third – the broadest and most in its infancy – the emergence of what is being called the smart city theorem. This capitalises on the use of systems that harness the opportunities of increased connectivity and the collection and curation of data to provide value (Cosgrave et al., 2013; IBM, 2014; Townsend, 2013)

However, disruption to private transport in the UK – even with recent wide-ranging policy pronouncements (BBC News, 2017) – measured on any one of these individual trends is, at present, slow. Electric cars only make up a minor share of the UK car market, with limited charging infrastructure outside of major urban areas and motorways (UK Department for Transport, 2008); short-term hire transport models have yet to be proved at a significant scale in the UK, beyond simpler modes such as for cycling (Kamargianni et al., 2016). Furthermore, smart cities are, in many cases, little more than a long term strategic aspiration for governments and policymakers, with few significant instances of demonstrators (including Glasgow and Bristol in the UK), many of which are too early in their lifetime to be able to provide any substantial conclusions about the value they produce from data (Caragliu et al., 2011).

Some of the most successful disruptive private transport initiatives of recent times can however often be observed combining two or three of these opportunities. AutoLib, the Paris-based EV car hire scheme offers single leg trips around the city and since 2011 has already grown to over 500,000 members and 4,000 cars across an extensive array of car nodes. Tesla Motors in the USA have also heavily emphasised new business models enabled by data and the role of new ownership models in their latest corporate strategy release (Musk, 2016). Existing literature has extensively examined each trend in its isolation but there is less exploration of combinations of two or more (see Figure 1), with even less focusing on the notion of synergy between the three trends as a principle. The idea of three significant issues needing to be considered in conjunction with one another is not a radical concept however, as seen in the inverse, but principally similar, 'energy trilemma' (World Energy Council, 2015). This paper – building upon previous work (Cooper et al., 2015a) with substantially extended theoretical framing, data and analysis – will focus on investigating the manifestations of the overlaps of these three opportunities within the context of the city of Bristol in the UK.

1.2 Electric Vehicles

Electric vehicles (EVs), driven by electric motors powered by a battery, have emerged as an environmentally sustainable alternative to ICEs. As well as reducing carbon emissions,

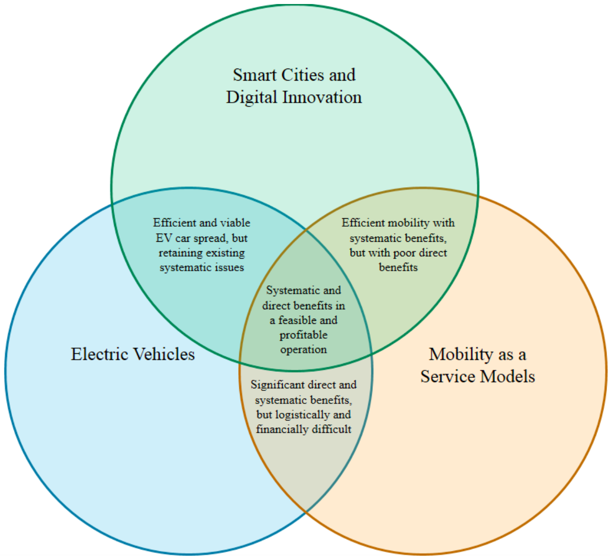

Figure 1: The proposed 'Tri-Opt' of positive opportunities to disrupt the private sector transport paradigm in developed countries.

EVs typically have lower noise and air pollution, can be cheaper to run per mile and reduce transport's dependency on fossil fuels (UK Parliamentary Office of Science and Technology, 2010). It is widely accepted that an alternate (and scalable) energy source is necessary for the UK transport network in the future, with electrification considered the most likely choice; by 2020, the UK's Department for Transport predicts there will be 1.5m EVs in use (UK Department for Transport, 2008).

Most of the world's major automotive manufacturers have released purpose-designed electric cars (different from ICEs that have a substituted EV power train); some have gone so far as to make significant strategic investment in the concept by releasing entire electric car ranges, such as BMW's i Series range. Personal cars and small commercial vehicles account for 13% of all UK carbon emissions (Lumsden, 2012) so the direct 'pump-to-tire' benefits of electric cars are highly significant. Legislation in many countries is a double-edged sword: penalising ICE users and incentivising the purchase of EVs. EVs bring with them several challenges, however: the purchase price of EVs, predominantly due to current battery technology, is yet to be comparable to an equivalent ICE; the embodied carbon of EVs, again due to the battery component, is typically higher than an equivalent ICE, and the generation of electricity to meet charging patterns is theorised to bring with it considerable logistical difficulties on national grids (Akhavan-Rezai et al., 2015; Su et al., 2011). Furthermore, some of the benefits, such as CO_2 savings, are dependant on the method of generation of the electricity used in the EV.

There are several barriers to the adoption of EVs. Some of which are psychological for the end user; ICE owners have shown range anxiety – a concern of 'running out of juice' (Office for Low Emission Vehicles, 2011; Yilmaz and Krein, 2012). Evidence rarely supports such concerns: 95% of all private vehicles journeys in the UK are < 25 miles (Office for Low Emission Vehicles, 2011), a distance current EVs are easily able to service. Other user perceptions include concerns over battery lifetimes, the risk of obsolescence from investing in a product from a rapidly advancing technology, and the higher price of EV purchase. Many also criticise an absence of second-hand EVs for purchase. Fleet vehicles accounted for 63% of all new vehicle sales in the UK in 2011; as such they are a dominant influence on the cars that are subsequently available for sale in the secondary purchase markets (Transport for London et al., 2012). There is a growing trend for EVs in fleet vehicles due to reduced running costs, so it is likely a substantive used EV market will start to emerge in the near future.

1.3 Digital Innovation and Smart Technologies

'Smart' as a mechanism is a contemporary and rapidly growing area of research; as such, a consensus on the concept's definition has yet to be reached. A review of academics, policy makers and industrial practitioners in the field suggests a recurring fundamental theme of the use of increased data (both in supply and quality) and connectivity to create value (Arup, The Climate Group, Accenture and Horizon, University of Nottingham, 2011; Batty et al., 2012; Buscher, 2014; Harrison and Abbott Donnelly, 2011; Komninos, 2002). The rise of interest in data-based value creation within cities can be related to a number of trends:

i) *The rapid acceleration in the production of data.* Several key societal developments, including the rise of wide-spread internet connectivity (particularly high-speed mobile connectivity) and social networking, has caused an exponential increase in data production; rapidly growing datasets have thus spurred experimentation as to their potential new uses. 'Big data' is regularly used to refer to such colossal quantities, and is sometimes defined as a data set big enough to be considered for use in smart value-producing systems. feasible (Dirks and Keeling, 2009; Hollands, 2008; Villa and Mitchell, 2010).

ii) *The rapid increase in the ability to collect more specific, higher-value data.* Improvements in sensor and transmission technology have resulted in data collection devices becoming more financially affordable and spatially practical (Townsend, 2013). The development of mesh networks, the mechanism of two-way communicating sensor nodes distributed over vast areas, can provide high resolution data facilitating accurate statements or the ability to reliably track and understand sensed activity. Furthermore, the internet of things (IoT) – defined as the notion of two-way connectivity being integrated in every day items – could enable transitions from machine-human-machine interaction to simply machine-machine.

iii) *Improvements in data storage and processing.* Storing and processing data is becoming significantly cheaper. These trends combine to enable complex, intensive analytics on data vast data sets – such as on the scale of a city – to be processed and presented for actioning fast enough to be deemed 'live'.

Discussion is increasingly refer to data as a raw material (sometimes going so far as to describe it as an emerging fifth 'utility'), creating the notion that data can and should be used as a primary input to a business model (Arup, The Climate Group, Accenture and Horizon, University of Nottingham, 2011). This may involve taking data across traditional 'silos' (Shapiro, 2006; Tsoukalas, 2008). Increasingly, this also represents the pressing focus on whole-life environmental impacts of ICTs (Cooper et al., 2015b). 'Creating value' can be defined in many ways, for example:

- *Faster processes:* for example, using traffic data to pro-actively update signs in real time, rather than the slow, reactive methods by which traffic is informally advised against taking certain routes.
- *Fairer:* for example, real time demand-based tolls for motorways, charging higher rates for peak travel times, or when air quality is particularly poor in the city, and conversely, lower rates at off peak times.
- *At lower cost:* for example, water pipes containing flow sensors to identify the accurate location of leaks as they emerge, rather than expensive and time-consuming excavations and visual inspections (Cosgrave et al., 2014).
- *Without human interaction:* For example, when a first aid dispatch can be made at the detection of a heart attack in a public space, rather than requiring on-lookers to assess the situation and intervene. This can improve instances of human error, social boundaries and subjective judgement although there is a discussion of the shortcomings of overly objective assessment in processes.

While there is acknowledgement that it is not without ethical and societal concerns (Bimber, 1990; Oatley et al., 2015), there is an extensive literature base documenting the potential impact of digital innovation, through these improvements, in the transport sector (Enoch, 2015).

One trend absent from this paper's analysis could be considered the issue of autonomous vehicles, and that if it were to be included it might best be considered within this category, or as an individual macro trend. It is acknowledged that in future revisions of this framework this consideration should be made, but is currently out of scope for this paper.

1.4 New Ownership Models

'Mobility-as-a-Service' has grown to be a concept that is specifically appreciated in modern transport dialogues (Transport Systems Catapult, 2016). It is best defined as a transition from a paradigm of relying on a product that is purchased to provide mobility functionality, to a service where the outcome of moving from one location to another is provided, disassociated from any requirement for asset ownership, and typically arranged on a journey-by-journey basis.

In other modes of private transport in the UK, such as bike use, an increasing number of citizens are participating in short term hire models of use, particularly in urban contexts. Rather than bearing the capital and logistical cost of owning a bike, individuals rent the bike from a node of bikes near the origin of their journey, complete their journey, and return the bike to a node near their destination. As such they are purchasing the outcome of mobility from one destination to another, or 'as-a-service'. Once seen as radical, examples such as London's cycle hire (also known colloquially as "Boris Bikes", after a high-profile Mayor of London) scheme has demonstrated not only the popularity of the operating model, but also the indirect benefits, illustrated by the significant increase in cycling in the city bringing health benefits, but also a degree of substitution for car journeys. A range of drivers have been suggested for the emergence of this paradigm:

- *Changing societal values:* whereby evidence has suggested a decrease in the cultural value placed on car ownership; conflict with an increased desire to live in vibrant urban areas within walking distance of workplace and other amenities and the spatial restrictions of car ownership in such scenarios (Jenks and Burgess, 2001).

- *Changing economic situations:* increasing costs of car ownership, particularly in insurance (particularly for young individuals) and fuel cost.
- *Changing effectiveness of privately-owned car transportation:* an increasing frustration with congested transport systems and an increasing desire to travel to A-to-B reliably, regardless of the specific comfort of one's 'own' motor vehicle.
- *Proof of concept:* Driven by commercial ventures showing the viability of alternate private transport paradigms. Traditional car hire companies in particular are beginning to explore short-term, distributed 'car club', return journey ('A-to-A' journeys) offerings, whereas emerging start-ups are offering complete A-B services, such as the aforementioned Autolib.

2 Methodology

2.1 Objectives

This paper thus sets out to achieve the following objectives:

i) To explore a range of use cases for how the opportunities in the aforementioned 'tri-opt' overlap in the UK's private transport, in combinations of two or three, to produce value.

ii) To understand, to a qualitative degree of accuracy, the varying value perceived by our stakeholders to be presented in the identified 'combination' use cases.

iii) To segment the use cases, considering both their characteristics, value potential and value certainty with a view to forming recommended policymaker actions.

2.2 Philosophy

This paper will take a systems-thinking perspective to consider the instances of when these trends create double and triple overlaps. For discovered instances, interaction of the tri-opts will be explored, and the value seen in the use case and certainty of that value measured. With respect to the definition and measurement of value, due the broad scope of this paper, value will be considered qualitatively through research facilitator review (detailed in the following section), with an emphasis on a use case's comparative value compared to other identified use cases. Value will be considered to all stakeholders within the system boundary; in this case the UK city of Bristol.

2.3 Methods

This paper implies a mixed methods approach, primarily but not exclusively – focused around a joint Bristol City Council and University of Bristol research study into the potential of a 'smart electric vehicle transport hub' – a proposed development that combined the three proposed trends on a physical site offering both public (bus and 'park and ride') and private (as-a-service electric car hire) transport services. The methods used are as follows:

- Five two-hour workshops with the presence of senior Bristol City Council staff, senior University of Bristol academics, and consulting engineers from built environment consultancy Arup;

- Ten semi-structured one hour interviews with a range of transport stakeholders in the city of Bristol, including bus operators, policy legislators, legal and financial professionals, all providing insight anonymously;
- A survey of 48 citizens of Bristol subscribed to Source West, an independent non-profit organisation representing the interests of citizens using electric vehicles;
- A range systems dynamics modelling to understand further detail value in a few specific use cases, explained in more detail when introduced.

Throughout the first two methodological approaches, uncovered use cases and the role of the 'opts' were documented, and the researchers attempted to score participant's views and reactions against two dimensions:

- *The value:* Participants were encouraged to voice their perceived scales of the benefit to all stakeholders within the city. Researchers then estimated this sentiment using an approximate scale of 0-100 where: 0 corresponded to no perceivable value in any circumstance; 50 a moderate but noteworthy value; and 100 a value of vast magnitude that could not perceivably be made tangibly larger.
- *The certainty:* Participants were encouraged to voice their perceived certainty of their value estimations. Researchers then estimated this sentiment using an approximate scale of 0-100 where: 0 corresponded to stakeholders suggesting their estimation was essentially random and dependent on a vast range of unpredictable external factors; 50 a relatively confident estimate but that was reliant on some external factors; and 100 a technical certainty that relied on no external factors.

The third and forth methodological approaches were used primarily to shape and detail certain use cases, and did not feed into scoring directly.

3 Results

3.1 Individual Uses Cases

3.1.1 Car Component State (Smart/MaaS/EV)

In the traditional car hire industry, it is common practice to run a maintenance program that involves inspection above the frequency that would be recommended for a privately-owned automobile, designed to reduce the likely car may suffer from a failure while hired by a customer.

Using mechanical health sensors – what could be considered a 'smart' element – attached to key components in the car, an operator of cars-as-a-service offering could gather insight on a car's mechanical state close to the quality of that offered by a human inspection, in real time. This has the potential to reduce the rate of failures in such a service. If the sensor coverage was sufficient enough, this could lead to cost savings through reduced servicing and also decrease turn-around times, important in a service that will have more frequent car hiring than a traditional arrangement. This is slightly exacerbated by an EV context, namely because the workings of EV power trains have less of a mechanical history than their ICE counterparts simply by way of being a newer technology.

3.1.2 Live Air Quality Management (Smart/MaaS)

Bristol City Council currently monitors air quality through a portfolio of permanent and semi-permanent sensor installations at points distributed around the city. In a typical UK urban environment, particularly one with no major heavy industry, air quality is primarily determined by road transport emissions, particularly those of diesel vehicles. It can be hypothesised that if it was possible to understand the distribution of vehicles in the city at any one point in time, it would be possible to estimate, the air quality across the entire city, to an acceptable degree of accuracy.

At present, in some areas of the city, car flow is monitored by car-recognising/ANPR cameras. Coverage however is poor and scaling this can be prohibitively expensive. Cars-as-a-service vehicles are likely to have near-identical behaviour to other cars on the road at that time. With a sufficient coverage of hire cars distributed among the main car parc, the total car distribution in Bristol could be extrapolated. Today other data sets exist for understanding car movements around a city (produced by mapping apps such as Google Maps), but this is not always available to cities, nor is it necessarily free. This could be complimented by data from air quality sensors directly affixed on to cars.

3.1.3 Live Accident Reporting (Smart/MaaS)

Cars could be fitted with impact sensors, altering a cars-as-service monitoring system that a car has suffered a crash, enabling them to immediately alert the authorities. A number of trends have significantly improved road safety in the UK over the last 20 years and combined with the relative rarity of such a scheme to have rural isolated crashes means it is unlikely that such a systems a tangible improvement in fatality rates from users of the service. Instead, it is more likely that the main benefit of such a system would an improved perception of safety by the user. It may also be possible that through connectivity to city transport systems, a system could alert traffic control teams of potential disruptions.

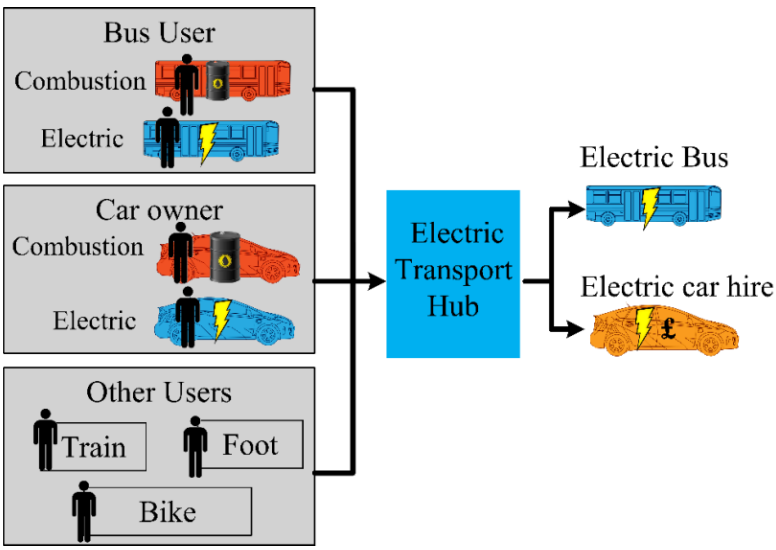

Figure 2: An overview of the functionality of Bristol's Smart Electric Transport Hub, structured by input transport modes (left) and output transport services

3.1.4 User Journey Data (Smart/MaaS)

Social media websites have shown that advertisement hit rates can be greatly improved by accurate targeting of the advert to the correct recipient. Depending on the medium of transport being used, historically this technique would be attempted by advertising at a particular time or in a particular geographical area. Today however, consumers are increasingly expressing preferences and specifics around their personal situation in data through social media networks, and it is possible to target individuals of a range of highly specific criteria, such as a specific relationship status, group affiliation or patrons of specific rival businesses. Facebook and Spotify are frequently highlighted examples of how these mechanisms can not only deliver high conversion rates – enabling the advertising to be sold at higher prices – but also enabler the sale of smaller, but still effective, advertising packages to smaller businesses. This mechanism could produce value in a cars-as-as-service offering in two identified ways.

Information on the journeys of car hire users, contextualised with time of use and demographic details, could be sold – wider privacy and ethical considerations notwithstanding – as valuable data companies in local retail and leisure sectors. Such clients can consider the expensive customer research they would otherwise have to undertake to obtain such data, and so a base price is conceivable. Alternatively, such data could be used in house in the form of targeted advertising in-vehicle. Organisations could partner with the service, offering promotional deals to users it believes it may be able to tempt to their business during or after the trip. This could be done in real time using spatial data e.g. when an individual approaches a particular business. The value creation could be twofold: the advertising organisations could pay for the in-car advertising rights if they are showing simply promotional material; if appealing deals are provided, more users would be more inclined to use the service. This second mechanism is likely to enjoy higher data consent rates from users as the value to them is more direct.

3.1.5 Demand-based Pricing (Smart/MaaS/EV)

An alternate method to control congestion is to bring economic forces to bare on when an individual chooses to travel. In practice, a MaaS could 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 a MaaS service of all the use cases addressed here. Furthermore, many ethical dilemmas exist. 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.

However another interpretation is around the ability to better control demand for the service, a key consideration for electric vehicles due to the fact that, even in the increasing affordability of fast chargers, EVs require considerably longer than ICE cars to transition from zero to full range capacity. Thirdly, this can also be used to manage car supply and demand between different nodes of car collection. There are a number of scenarios where the ability to maintain a serviceable fleet at a node could be jeopardised:

1. *Inclement driving conditions:* Compared to ICEs, EV's energy consumption per mile is more susceptible to influence from weather conditions. Colder weather can have negative effects on the motor and battery performance. Furthermore, car cabin heaters in EVs do not have engine heat stream to redirect, so additional power from the battery is required to generate this, measured to be as much as 15% (UK Department for Transport, 2008). Live battery data could enable the

cars-as-as-service management system to know the exact power use of a journey and thus the expected battery use available at the end of a journey.

2. *Congestion:* High levels of traffic, resulting in 'stop-start driving can significantly decrease the efficiency of an EV, although the effect is not as pronounced as with an ICE as an EV powertrain can turn off and on with less energy loss. Congestion also decreases journey time. Car speed data and GPS location data could inform the booking management system when a car is likely to have reduced efficiency, and when it is unlikely to be back at a node when expected.

3. *Satellite navigation:* Knowing the intended destination of a user can help pre-empt different levels of EV occupancy at nodes, and advise where a space needs to be made available. Furthermore, live satellite navigation data can advise what route is taken, and how this effects the arrival time and level of charge at arrival.

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. Insight from these and other scenarios will advise the cars-as-a-service operation system of when which EVs are likely to be at which nodes and with what charge, allowing interventions that adjust pricing at different nodes to ensure space at current destination nodes and availability of charged cars across all nodes. An example of a simple dynamic pricing formula can be seen in Figure 3.1.5 whereby the 'smart power' determines the degree of extremity in the dynamic pricing. A simulation exploring the potential impact of demand-based pricing based on such an algorithm, on revenue and variance of booking density, for a designed service of 'smart EV MaaS' as part of the *Bristol Smart EV Hub* project, can be seen in Figure 3.

$$Price\ (per\ hour) = Standard\ price * \left(\frac{current\ popularity}{average\ popularity}\right)^{smart\ constant}$$

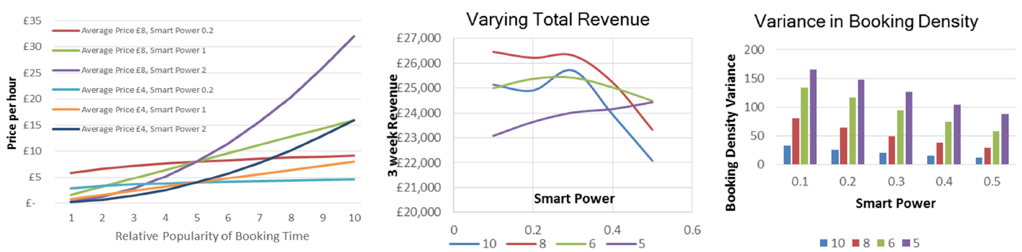

Figure 3: Data regarding varying dynamic pricing rates (left) derived from Figure 3.1.5 and their effect on revenues (centre) and booking densities (right). Collected during the *Bristol Smart EV Hub* project.

At least on theoretical customer behaviour, it is possible to create a scenario through dynamic pricing where both total revenue is increased and bookings are more evenly distributed. This mechanism could be made stronger; or seen to be more of a 'carrot' than a 'stick' strategy by the use of reduced parking costs in non- or limited-nodal MaaS systems.

3.1.6 Driving Styles and Usage Habits (Smart/EV/MaaS)

As a high growth market, the EV market is currently undergoing heavy R&D investment. As a distinctly different driving experience, automotive designers are particularly interested in how users interact with the vehicle (Ferreira et al., 2013). Such data is not currently commonplace and as such; to create this car manufacturers spend capital on customer surveys, on-road testing and other investments.

A similar situation can be observed in the in the car insurance industry; at present relatively few car insurers offer cover for EVs due to a poor understanding of their risk. Those that do offer prices above the ICE equivalent average 16-26% more. It is unclear if EV owners drive in an identical manner to combustion car owners, or if they are at a higher risk of collision due to lower noise and potential higher accelerations than combustion cars. Furthermore, many fundamental components of the EV have yet to come close to their expected end of life, so it is risky for insurers who do not know if the vehicles will reach their rated life.

The UK's National Grid could derive value in how EV charging in a cars-as-service models has an impact on the grid, steering their strategic investment accordingly. Although information is available around how privately-owned EVs require charging users (Darabi and Ferdowsi, 2013; Kennel et al., 2012), EVs in frequent trips throughout the day could have distinctly different charging requirements. The value of this insight also extends to regional distribution network operators, who hold the responsibility of ensuring local networks can service supply, and the nodal distribution of this services cars could have significant impacts upon that. It is reasonable to assume there is value in these data sets to the operator of an EV MaaS system, through external sale, if a data strategy was in place to collect, store and market this.

3.1.7 Dynamic Traffic Routing (Smart/MaaS)

Understanding the average speed of a road's cars allows the city's transport management to predict the related areas of congestion. The necessary resolution of this is much lower i.e. the speed of a given stretch of road is largely similar for all vehicles driving along it. Knowing such information in real time, the city transport management team can employ data-based traffic management techniques. One of the most common of these is the notion of dynamic traffic re-routing. Road users are directed to the fastest route to a given location by being mindful of congestion. The car hire scheme takes this concept one step further, as it will be possible to understand where individuals are planning on driving in advance. With this information, mitigation actions that would previously be considered to have too long a lead time even in the 'live' mode can be implemented. For example, higher use of contraflow lanes that can be dynamically adjusted to allow for the particular nature of the rush hour traffic, increased public transport frequencies to help move demand off the roads, or variable speed limits to maximise flow rates and relieve bottlenecks.

Much of the infrastructure necessary to facilitate this has already been tested at scale: dynamic lane direction has proven successful on the M6 (intercity) motorway around Birmingham and the M25 London orbital motorway in the UK, with extensive supporting evidence about its dynamic speed limit interventions. This infrastructure could be improved in effectiveness from data that was faster and more accurate than existing, predominantly analogue sensing techniques. A criticism of this concept might be that such data sets are currently collected by global technology firms such as Google. Such data however is not readily available to cities, and when it does, it typically comes with a substantial cost. A MaaS service would have access to this data and could provide it to the city's transport team.

3.1.8 Grid Balancing (EV/Smart/MaaS)

Grid balancing is a generalised term for the concept of taking action to mitigate for surpluses of supply or shortages in demand in a region or nations electricity system. In some definitions, balancing involves transferring power into the grid, but many techniques of simply avoiding drawing power (a.k.a. *shaving*) or moving the demand to another period (a.k.a. *shifting*) are considered balancing by the UK Government (UK Department of Energy & Climate Change, 2014). The challenge of balancing the network is becoming much larger with more distributed generation and larger power demands. Many stakeholders in the UK's energy industry are increasingly providing financial incentives for these services and view it as an important challenge of the future. Almost all of these solutions involve some aspect of a 'smart grid', i.e. that data is used in the management of these interventions.

This is difficulty is highly relevant to EVs as they represent a growing load on the grid; some studies have suggested even moderate uptake of EVs might increase national power demand by up to 23% in some areas by 2021 (Paffumi et al., 2015). However, of greater concern based on early observations that EVs will increase the variation (essentially the peakiness) in grid demand, a quality that is harder to service than total demand. However, at the same time their potential to be used as charge storing devices enables a situation whereby theoretically, rather than being seen as a burden on the grid which needs to be minimised, they could be seen as a positive asset to provide charge to meet demand at peak times. Typically batteries have a very quick response rate to grid requirements, something other balancing solutions can lack.

Crucially for our study, this would be exacerbated in a MaaS offering, whereby the value of the charge to the grid at that time is factored into the cost of someone instead using that charge to drive the car. The cars could then be used as grid balancing charge storage in periods of lower demand. Logistically, a MaaS arrangement would have EVs plugged in by default (requiring no manual intervention as likely with privately-owned EVs). Furthermore, such systems would also typically have large numbers of EVs connected to the grid on connections with substantial voltage capacity, facilitating sudden charge and discharge actions.

This potential for consideration as an asset to the grid comes with the caveat that required charging for the car's actual purpose can be sufficiently shifted to be of negligible impact. This is compounded by the context that many of the business models around balancing systems have yet to achieve commercial viability, and may not develop so in the UK for at least 10 years. This, along with the general penetration of EVs – MaaS or otherwise – are important factors to consider for this use case, but are not relevant to our scope of examining trend overlaps.

4 Use Case Value Comparison

4.1 Workshops/Interviews

It is clear there is significant variation in the perception of value in the identified use cases, and the certainty to which we understand this value and the path to realise it; these are presented in Figure 4. From observation of the results, three categories can be generalised:

- *Segment 3*, those that have by far the greatest benefit but are also the most uncertain. Typically these have the highest critical masses and require considerable, cross-sector stakeholder buy-in. However, their potential value could be described as extreme. Discussion highlighted how these, typically have the most diverse forms of value, spanning environmental, social and economic value, beyond simply financial benefits. While, due to the substantial barriers, these concepts are highly unlikely to be implemented immediately, their significant potential cannot be ignored.

- *Segment 2*, with moderate benefit whose uncertainty is somewhat less and who enjoy good overall value/certainty ratio. These are typically mechanisms that involve the collection, management and external vending of data. The value of these will be dependant on how legal and contractual norms around data trading evolve. Furthermore, cities, including Bristol, have launched open data initiatives, where certain public sector data sets freely available for use. There is an ongoing debate about how data monetisation strategies, such as these, are compatible with city open data ambitions.

- *Segment 1*, with relatively low value but relatively high certainty. This group are best characterised as 'operational' changes, and as such require relatively little collaboration across stakeholder groups.

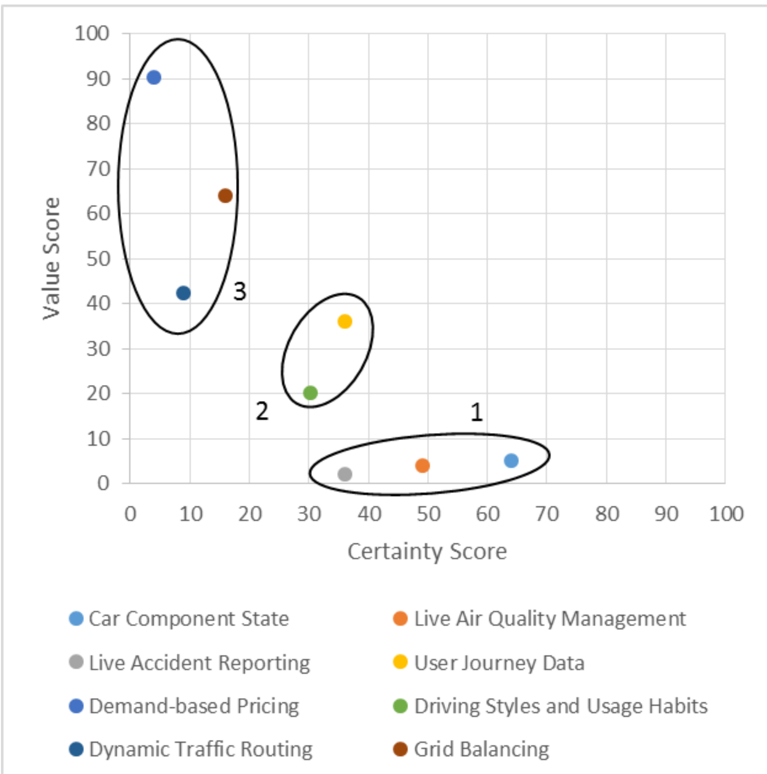

Figure 4: Results from workshop exercises on assigning qualitative value scores to use cases (note: log scale)

Graphical approximations of these characteristics across the three segments can be seen in Figure 5.

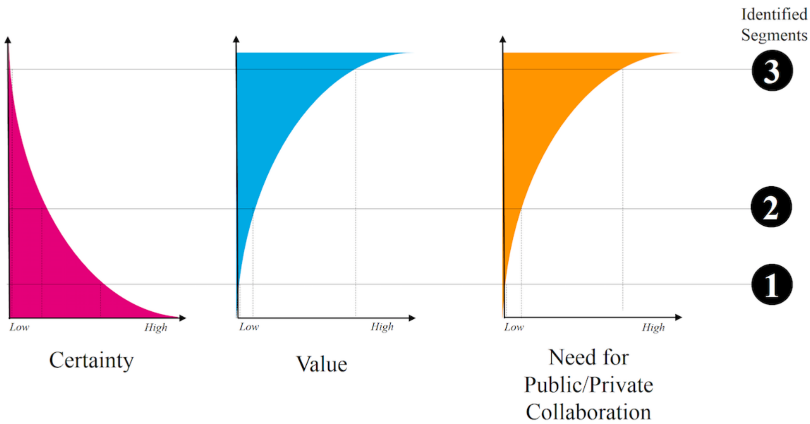

Figure 5: Generalised relationships across identified segments

5 Conclusion

There is clearly synergistic value within the overlaps of the proposed 'Tri-Opt', confirming the original hypothesis. However it appears the specifics of this are somewhat different to initial speculation. The findings suggest concepts that combine MaaS offerings and digital innovation are the main focus of value creation which was favoured over MaaS, EV and digital tri-overlaps. While we can still conclude that the notion of the triple overlaps exist as an area to be considered, the original equal status hypothesised is incorrect, and that EVs are perhaps considered as a simply 'significant' development that is set within the context of two more transformative opportunities of MaaS and digital innovation. Reviewing the concepts that have emerged through our methodology, value appears to span a wide range, but is overall significant. Certainty is also variable but generally averages at a lower point, as is to be expected when considering that these are all significant changes to the norm that are at best very uncommon in terms of current implementation.

With respect to recommendations that can be inferred from the findings within this paper:

- *Segment 1* should be considered good operational practice for smart, MaaS EV services. However they are not transformative, and generally provide limited value, so should not be considered high priority focuses.
- *Segment 2* should be considered as positive additional revenue streams for smart, MaaS EV services. In particular, they may be beneficial for improving business cases to the degree that such services can attract investment and be launched, so releasing the individual benefits of each "Opt". While offering good value for relative certainty, they are not transformative in and of themselves and should not be considered end goals.

- *Segment 3* can be considered long term strategic focuses that have transformative value, and have underlying mechanisms that span beyond transport. Currently highly uncertain, understanding these, conceptually, should be a long term, pan-city, high priority aspiration.

It is important to note that this paper does not set out to define the value cases of the individual "Opts" themselves – such as reduced sunk-cost-induced car use in a MaaS model – and is designed to be a study of interaction of the three opportunities rather than appraisal of each concept by itself – of which there is extensive literature already in existence as explored in Section 1. These recommendations however should be appreciated within the context of the individual benefits of MaaS, smart cities and digital innovation and electric vehicles.

Our results suggest that there are significantly more barriers than enablers at play in these double and triple overlapping concepts. Of most significance in the eyes of the participants, and of most relevance to the highest-value segment of use cases, is the need for public and private sector collaboration. It seems reasonable to presume this is a barrier for 'as-a-service' and digital innovation concepts across a range of city services.

6 Future Work

For application beyond transport, it is recommended that the underlying generic mechanisms at play that create value are further explored. The particular emphasis on MaaS and digital innovation suggests 'digitally-enabled innovative business models' may be the best starting point for considering these. Taking away the transport context, several mechanisms be observed in our research including: sharing of data to mutual benefit (e.g. driving habits), supporting new service delivery models that bring public benefit (e.g. dynamic car routing) and assistance of delivering public policy (e.g. demand-based pricing to reduce congestion).

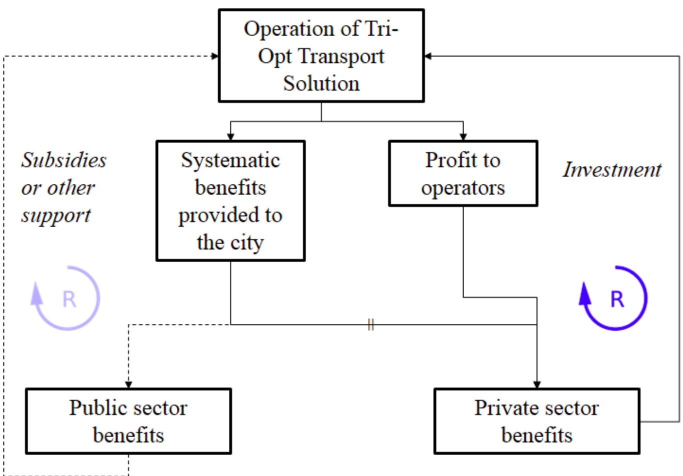

Figure 6: A causal loop diagram articulating the investment/value dilemma of some tri-opt transport solutions.

Little or no research could be found that defines a framework of these mechanisms and there is a significant evidence base that private sector participation in city digital initiatives is a regular criticism by the public sector (Martin, 2016), thus it can be hypothesised there is value in understanding this issue better. Related to this, digitally-enabled public and private collaboration needs to be understood better, as it currently stands as the major barrier. The distribution of value/risk/investment identified as part of this, and articulated in a simplified causal loop diagram in Figure 6, need to be further investigated.

Acknowledgments

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