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 of the pump-to-tire shortcomings, 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 per single leg of a journey, also addressing systematic impact such as residential parking and social division. Thirdly, the rise of 'smart city thinking', the concept that increased connectivity, data and smart grids can be harnessed to create value, especially in 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 utilise 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 comparative value, and segmentation is undertaken to characterise and generalise groups of concepts to inform recommended stakeholder actions. We demonstrate that synergistic overlaps are many and they create significant value; thus the 'Tri-Opt' notion should be investigated further. 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. It is thus highly recommended that public-private sector collaboration in private transport – within a context of digital innovation – electric vehicles, smart grids and mobility as a service model, is subject to further research and investigation.

I. INTRODUCTION

A. Problem Space

A GROWING corpus of research 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 fifty years in its current form, in the face of economic, social, and environmental pressures [1]–[3]. Several distinct trends have emerged a as potential disruptors in existing research. Three in particular are identified and focused upon within this paper; firstly, the emergence of electrical motors as the primary alternate powertrain for private automobiles [4], [5]. 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' [6]. 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 [7]–[9] where disruption to private transport, 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 [10]; short-term hire transport models have yet to be proved at a significant scale in the UK, beyond simpler modes such as for cycling [11]; and smart cities are, in many cases, little more than a long term strategic aspiration for governments and policymakers, with some instances of demonstrators (including Glasgow and Manchester 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.

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 one-directional trips around the city and since 2011 has already grown to over 500,000 members and 4,000 cars. Tesla Motors have also heavily emphasised new business models enabled by data and the role of new ownership models in their latest corporate strategy release [12]. Existing literature has extensively examined each trend in its isolation, and to a limited degree there is exploration of combinations of two, but there is almost no consideration of triple-overlaps (see Figure 1), nor of 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' [13]. This paper – substantially extending previous work [14] – will focus on investigating the manifestations of the overlaps of these three opportunities within the context of the city of Bristol in the UK.

B. Electric Vehicles

Electric vehicles (EVs) have emerged as an environmentally sustainable alternative to ICEs. EVs are driven by electric motors powered by a battery. As well as reducing carbon emissions, EVs typically have lower noise and air pollution, can be cheaper to run per mile and reduce transport's dependency on fossil fuels [15]. 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 [10].

Most of the world's major automotive manufacturers have released purpose-designed electric cars (different from ICEs
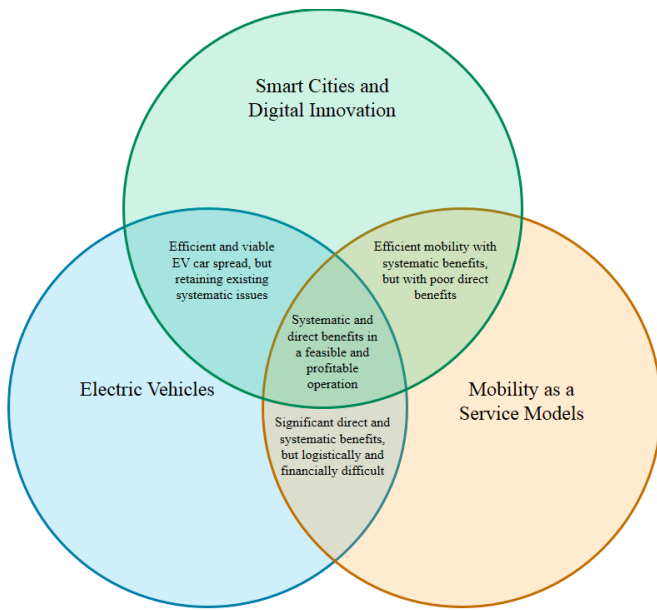
Fig. 1. The proposed 'Tri-Opt' of positive opportunities to disrupt the private sector transport paradigm in developed countries.

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 [16]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 [17], [18]. 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' [19], [20]. Evidence rarely supports such concerns - 95% of all private vehicles journeys in the UK are ¡25 miles [19], 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 used 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 [21]. There is a growing trend for EVs in fleet vehicles due to reduced running costs, so it is likely a tangible used EV market will start to emerge in the near future.

C. 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 and connectivity to create value [22]–[26]. The rise of interest in data-based value creation within cities can be related to a number of trends:

1) *The rapid acceleration in the production of data* Several key societal developments, including the rise of widespread 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 [27]–[29].

2) *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 [7]. The development of mesh networks, the mechanism of 2-way 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 - defined as the notion of 2-way connectivity being integrated in every day items - could enable transitions from machine-human-machine interaction to simply machine-machine.

3) *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 [23]. This may involve taking data across traditional 'silos' [30], [31]. Increasingly, this also represents the pressing focus on whole-life environmental impacts of ICTs [32]. 'Creating value' can be defined in many ways, for example:

- *Faster processes:* for example, using traffic data to proactively 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 times 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 [33].

- *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 [34], [35], there is an extensive literature base documenting the potential impact of digital innovation, through these improvements, in the transport sector [36].

D. New Ownership Models

'Mobility as a Service' has grown to be a concept that is specifically appreciated in modern transport dialogues [6]. 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 Londons cycle hire (also known as "Boris Bikes") 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 [37].
- *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 entire by-leg services, such as the aforementioned Autolib.

II. METHODOLOGY

A. Objectives

This paper sets out to achieve the following objectives:

1) 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.
2) To understand, to a qualitative and relative degree of accuracy, the varying value perceived by our stakeholders to be presented in the identified use cases.
3) To segment the use cases, considering a combination of their characteristics and value potential, with a view to forming recommended policymaker actions.

B. Philosophy

This paper will take a systems thinking perspective to divergently consider the instances of when these trends create double and triple overlaps. With respect to the definition and measurement of value, due the broad scope of this paper, value will be considered qualitatively, with an emphasis on a use case's relative value compared to other identified use cases. Value will be considered to all stakeholders within the system boundary – in this case the city of Bristol, UK. To add rigor to this process, during engagement with stakeholders, the framework shown in Figure 2 was used, combining three approaches for considering value.
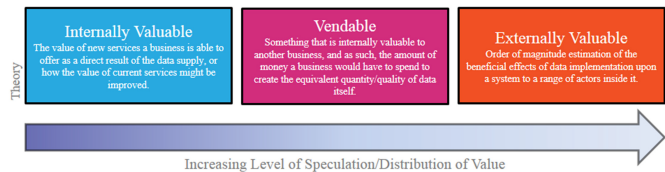

Fig. 2. Valuation methods

C. Methods

This paper implies a mixed methods approach, primarily but not exclusively – focused around a joint Bristol City Council and Bristol University research study into the potential of a 'smart electric vehicle transport hub' – a 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;

III. RESULTS

A. Individual Uses Cases

1) Car Component State (Smart/MaaS): 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 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.

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) Live Accident Reporting (Smart/MaaS): The hired cars could also be fitted with impact sensors, altering the 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 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 such a system could also alert traffic control teams of potential disruptions.
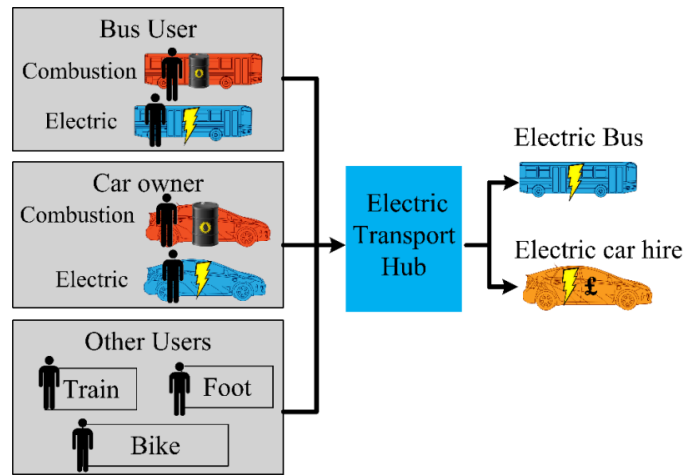

Fig. 3. An overview of the functionality of Bristol's Smart Electric Transport Hub, structured by input transport modes (left) and output transport services

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 regularly cited case studies 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 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 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.

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 hire cars 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, EVs 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 are do not have an engine heat stream to redirect, so additional power from the battery is required to generate this, measured to be as much as 15% [10]. 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. A simulation exploring the potential impact of demand-based pricing on revenue and variance of booking density, for a designed node

of an smart EV MaaS node, can be seen in Figure 4.

$$Price\ (per\ hour) = Mean\ Price\ (per\ hour) * \left(\frac{Relative\ Popularity}{Average\ Popularity}\right)^{Smart\ constant}$$

As can be observed, it is possible to create a scenario 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.

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 [38]. 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 [39], [40], 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.

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
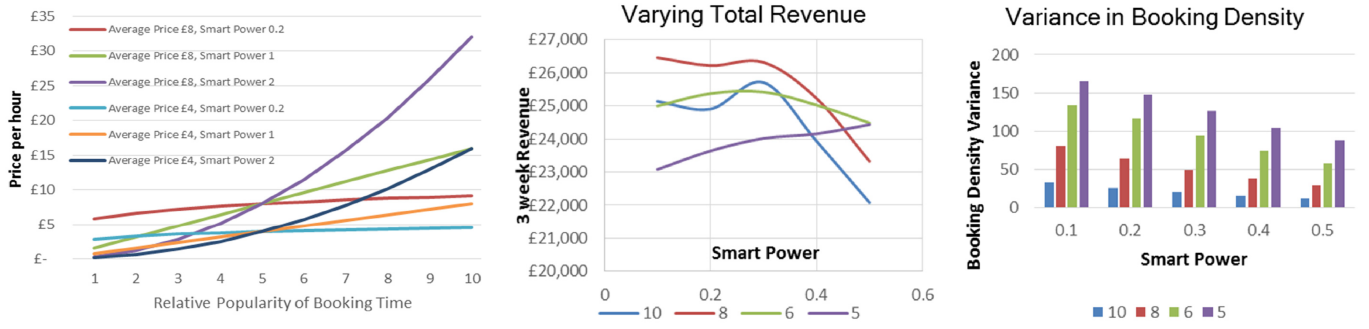
Fig. 4. Data regarding price sensitivity, customer flexibility and estimated footfall collected during the *Bristol Smart EV Hub* project.

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 in Birmingham and the M25 has 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 digital 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.

8) Grid Balancing (EV/Smart/MaaS): Grid balancing is a generalised term for the concept of taking action to mitigate for surpluses or shortages in a region or nations electricity generation. In some definitions, balancing involves transferring power into the grid, but many techniques of simply avoiding drawing power (aka. 'shedding') are considered balancing by the UK Government [41]. 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.

This is increasingly 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. However, of greater concern is how 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 rather than being a burden on the grid which needs to be minimised, they can be 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. 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.

IV. USE CASE VALUE COMPARISON

A. 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 5. 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.

Graphical approximations of these characteristics across the three segments can be seen in Figure 6.

V. CONCLUSION

There is clearly synergistic value within the overlaps of the proposed 'Tri-Opt', confirming the original hypothesis.
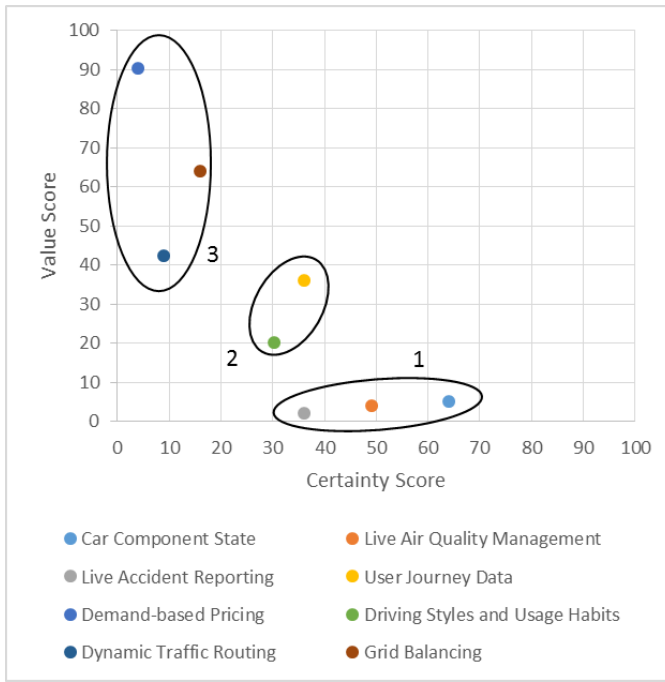
Fig. 5. Results from workshop exercises on assigning qualitative value scores to use cases (note: log scale)
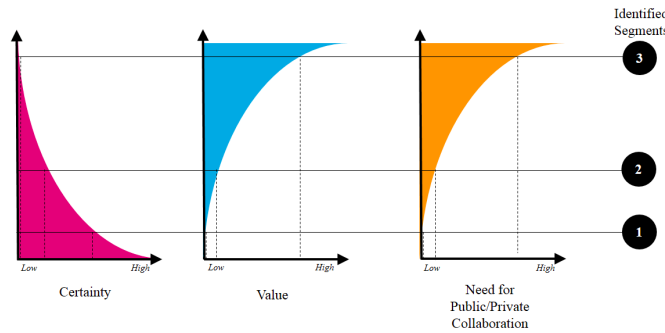

Fig. 6. Generalised relationships across identified segments

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 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.

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 I. 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.

VI. FUTURE WORK

For application beyond transport, it is recommended that the underlying generic mechanisms at play that create value are 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 can 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).

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 [42], 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 7, need to be further investigated.

ACKNOWLEDGMENT
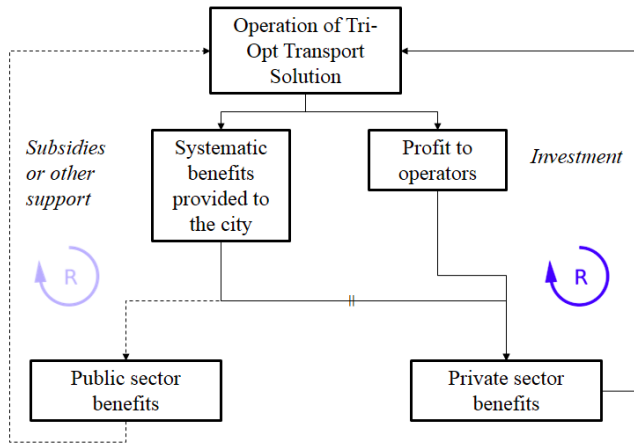
Fig. 7. A causal loop diagram articulating the investment/value dilemma of some tri-opt transport solutions.

REFERENCES

[1] W. Lerner, "The Future of Urban Mobility: Towards networked, multi-modal cities of 2050," Arthur D. Little Future Lab, Tech. Rep., 2011.

[2] F.-J. Van Audenhove, O. Korniichuk, L. Dauby, and J. Pourbaix, "The Future of Urban Mobility 2.0: Imperatives to shape extended mobility ecosystems of tomorrow," Arthur D. Little Future Lab, Tech. Rep., 2014.

[3] C. Black, G. Parkhurst, and I. Shergold, "The EVIDENCE project: Origins, review findings and prospects for enhanced urban transport appraisal and evaluation in the future," *World Transport Policy & Practice*, vol. 22, no. 1-2, pp. 6–11, 2016.

[4] E. Paffumi, M. De Gennaro, G. Martini, and H. Scholz, "Assessment of the potential of electric vehicles and charging strategies to meet urban mobility requirements," *Transportmetrica A: Transport Science*, vol. 11, no. 1, pp. 22–60, 2015.

[5] T. Gnann, P. Plötz, S. Funke, and M. Wietschel, "What is the market potential of plug-in electric vehicles as commercial passenger cars? A case study from Germany," *Transportation Research Part D: Transport and Environment*, vol. 37, pp. 171–187, 2015.

[6] Transport Systems Catapult, "Mobility as a Service: Exploring the Opportunity for Mobility as a Service in the UK," UK Transport Systems Catapult, Tech. Rep., 2016.

[7] A. M. Townsend, *Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia*. W. W. Norton & Company, 2013.

[8] E. Cosgrave, K. Arbuthnot, and T. Tryfonas, "Living Labs, Innovation Districts and Information Marketplaces: A Systems Approach for Smart Cities," *Procedia Computer Science*, vol. 16, pp. 668–677, 2013.

[9] IBM, "Smarter Cities," http://www.ibm.com/smarterplanet/nz/en/smarter_cities/ideas/, 2014, (retrieved 31 July 2016).

[10] 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.

[11] M. Kamargianni, W. Li, M. Matyas, and A. Schäfer, "A Critical Review of New Mobility Services for Urban Transport," *Transportation Research Procedia*, vol. 14, pp. 3294–3303, 2016.

[12] E. Musk, "Master Plan, Part Deux," https://www.tesla.com/en_GB/blog/master-plan-part-deux, 2016, (retrieved 31 July 2016).

[13] World Energy Council, "Energy Trilemma Index," 2015.

[14] P. Cooper, T. Crick, and T. Tryfonas, "Smart Data-Harnessing for Financial Value in Short-Term Hire Electric Car Schemes," in *Proceedings of 10th IEEE System of Systems Engineering Conference*. IEEE, 2015.

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

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

[17] W. Su, H. Eichi, W. Zeng, and M.-Y. Chow, "A Survey on the Electrification of Transportation in a Smart Grid Environment," *IEEE Transactions on Industrial Informatics*, vol. 8, no. 1, pp. 1–10, 2011.

[18] E. Akhavan-Rezai, M. F. Shaaban, E. F. El-Saadany, and F. Karray, "Demand response through interactive incorporation of plug-in electric vehicles," in *IEEE Power Energy Society General Meeting*, 2015.

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

[20] M. Yilmaz and P. T. Krein, "Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles," *IEEE Transactions on Power Electronics*, vol. 23, no. 5, pp. 2151–2169, 2012.

[21] 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.

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

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

[24] 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*, 2011, pp. 7–22.

[25] 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.

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

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

[28] 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.

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

[30] 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.

[31] 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*. IEEE, 2008.

[32] P. Cooper, T. Crick, T. Tryfonas, and G. Oikonomou, "Whole-Life Environmental Impacts of ICT Use," in *Proceedings of IEEE International Workshop on Green Standardizations for ICT and Relevant Technologies*. IEEE, 2015.

[33] 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.

[34] B. Bimber, "Karl Marx and the Three Faces of Technological Determinism," *Social Studies of Science*, vol. 20, no. 2, pp. 333–351, 1990.

[35] G. Oatley, T. Crick, and D. Bolt, "CCTV as a Smart Sensor Network," in *Proceedings of 13th IEEE International Conference on Dependable, Autonomic and Secure Computing*. IEEE, 2015.

[36] M. P. Enoch, "How a rapid modal convergence into a universal automated taxi service could be the future for local passenger transport," *Technology Analysis & Strategic Management* , vol. 27, no. 8, pp. 910–924, 2015.

[37] M. Jenks and R. Burgess, Eds., *Compact Cities: Sustainable Urban Forms for Developing Countries*. Routledge, 2001.

[38] J. C. Ferreira, V. Monteiro, and J. Afonso, "Vehicle-to-Anything Application (V2Anything App) for Electric Vehicles," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 3, pp. 1927–1937, 2013.

[39] F. Kennel, D. Görges, and S. Liu, "Energy Management for Smart Grids With Electric Vehicles Based on Hierarchical MPC," *IEEE Transactions on Industrial Informatics*, vol. 9, no. 3, pp. 1528–1537, 2012.

[40] Z. Darabi and M. Ferdowsi, "An Event-Based Simulation Framework to Examine the Response of Power Grid to the Charging Demand of Plug-In Hybrid Electric Vehicles," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 1, pp. 313–322, 2013.

[41] UK Department of Energy & Climate Change, "Smart Grid Forum's Smart Grid vision and routemap," Tech. Rep., February 2014.

[42] C. J. Martin, "The sharing economy: A pathway to sustainability or a nightmarish form of neoliberal capitalism?" *Ecological Economics*, vol. 121, pp. 149–159, 2016.