Research in Transportation Economics 48 (2014) 357–363

Contents lists available at ScienceDirect

Research in Transportation Economics

journal homepage: www.elsevier.com/locate/retrec

Developing a viable electric bus service: The Milton Keynes demonstration project

John Miles [a], Stephen Potter [b,*,1]

[a] Department of Engineering, The University of Cambridge, UK
[b] Department of Engineering and Innovation, The Open University, UK

ARTICLE INFO

Article history:
Available online 11 October 2014

Keywords:
Electric bus
Inductive charging
Carbon emissions
Business model

ABSTRACT

Buses can be a serious source of city centre air pollution. Electric buses deliver zero emissions but, because of the time required to recharge, more buses are needed for a given timetable than diesel counterparts, so making mainstream electric bus operations prohibitively expensive.

Early 2014 saw the implementation in Milton Keynes of an electric bus service designed to overcome this problem. An entire bus route has been converted to electric operation with inductive charging at bus layover points. This permits the use of smaller and less expensive battery packs allowing the electric buses to operate continuously all day. This approach significantly reduces the cost of introducing a pure electric bus fleet.

This study not only provides an example of how the electric bus problem can be resolved technically. It also addresses the business structures required to deliver sustainable transport, introducing a different commercial model to that which is traditionally used for bus service delivery. This raises important points for regulatory and innovation policy. There is government support for sustainable transport technologies, but successful delivery in the commercial environment requires new institutional structures and business models as well. The Milton Keynes project has sought to develop such a structure.

1. The drive for low carbon buses

Despite the development of increasingly stringent emission standards, diesel buses remain a serious concern for air pollution in urban areas. This is why they have been included in initiatives such as the London Low Emission Zone (Ellison, Greaves, & Hensher, 2013), where emission of Nitrogen Oxides from diesel vehicles remains a persistent concern (McGrath, 2014). The use of cleaner CNG and LPG-powered buses has found favour in a number of European states and is seeing growing use in China. Concerns over emissions from city buses have been reflected in local transport policy debate and discussion; for example, in Oxford, buses are considered to be a key contributor in making the city centre street of St Aldate's the ninth most polluted street in the UK (Airs, 2013).

Although engine and cleaner fuel technologies can be employed to mitigate air quality issues, increasingly stringent carbon reduction targets require a shift towards fuels that can be largely decarbonised. In the UK, the *King Report* (King, 2007) was a crucial turning point in policies for vehicle and fuel technologies to decarbonise road transport. For cars, this report concluded that hydrogen and biofuels would not deliver the rapid decarbonisation required. This led to a revision of policies to focus upon battery electric and hybrid technologies for the short-medium term. A government-industry strategy emerged over the next two years epitomised by the 2009 *NAIGT Report* on the future of the automotive industry (NAIGT., 2009). This set out a technology development 'roadmap' anticipating cleaner internal combustion technologies followed by uptake of battery electric and plug-in hybrid vehicles and then, much later, joined by hydrogen fuel cell vehicles.

There are valid issues concerning carbon emitted in generating electricity and in the manufacture of hydrogen, but unlike fossil fuels, production of electricity and hydrogen has the potential to be substantially decarbonised. A similar policy process has unfolded in a number of other European countries in the last decade, with support measures put in place for battery electric vehicles and public recharging infrastructure.

In the UK, the *Low CO_2 Technology Roadmap for Buses* (Atkins, Cornwell, Tebbutt, & Schonau, 2013) applies to the bus sector the same approach as in the NAIGT report. This report identifies a series

* Corresponding author. Department of Engineering and Innovation, Faculty of Maths, Computing and Technology, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK. Tel.: +44 (0)1908 652634.
E-mail address: stephen.potter@open.ac.uk (S. Potter).
1 Presenting author.

http://dx.doi.org/10.1016/j.retrec.2014.09.063
0739-8859/

of lower carbon technologies, from those delivering a marginal reduction in CO_2 compared to a diesel bus, through to ones with a substantial decarbonisation potential. Hybrid vehicles (e.g. as used presently in London and Oxford) produce a 20–40% reduction in 'well to wheel' CO_2, but the only technologies to offer a high enough decarbonisation potential to address the targets set in the 2008 Climate Change Act (a 40% cut by 2020 and an 80% CO_2 cut by 2050) are biomethane, renewably-sourced hydrogen or battery electric vehicles.

2. The challenge for a battery electric bus design

As with previous studies on low CO_2 vehicle technologies, the *Roadmap for Buses* report noted the pattern of a higher capital cost which is counterbalanced by lower fuel and other operating costs. Battery-electric vehicles cost about twice that of their diesel equivalent, with the cost of batteries responsible for most of the difference. There is a payback period before the high capital costs are recouped in lower operating costs. This means that, commercially, high distance applications represent the most viable market sectors for low carbon vehicles. Urban buses typically cover 60,000–100,000 km per year (around 200–300 km per working day) and so would appear to be a viable market sector for a low CO_2 technology like battery-electric traction. However, for a large road vehicle like a bus, range limitations and recharging times of battery packs mean that such high utilisation is very difficult to achieve. An electric bus will have covered little more than a half of its daily operational distance before a lengthy recharge is needed. The battery-electric buses that have been used in a number of cities thus tend to operate on short routes and often require a larger fleet to allow for additional downtime for recharging (see Fig. 1). For example, the electric buses operating the Coventry Park-and-Ride shuttle service requires two vehicles to operate the service, with a third electric bus on charge. This three for two replacement of diesel buses substantially increases both the capital and operational costs involved (each bus typically requires two drivers for a normal working day).

The recently introduced use of BYD electric buses on two short central London routes has involved a different approach (Transport News Brief, 2013). Here, electric buses are used to enhance peak frequency, so they operate in the morning peak alongside the core diesel fleet, return to a depot to recharge ready for running in the evening peak and then go back to the depot again for an overnight charge. This pattern suits operating requirements, but such low utilisation means it is unlikely that the high capital cost of purchasing the buses can be offset by reduced fuel costs.

These examples illustrate why achieving an effective operational range for electric buses has been a central issue in a number of studies. For example, in looking for an application in Taiwan, Tzeng, Lin, and Opricovic (2005) concluded that hybrid electric buses would be the most suitable of available technologies, but the best alternative would be a pure electric bus if it could provide an acceptable range.

The range issue has thus been an important component of the Mitsui Arup Sustainable Projects (MASP) research that has informed the Milton Keynes electric bus demonstration project. But crucially this has set the demanding goal of designing a battery-electric bus system that can not only technically match a diesel bus, but also match it economically. This is not for small electric buses, but for a medium-sized buses carrying 40–50 passengers in mainstream bus operations.

MASP first studied a variety of urban bus routes operating in some of the world's major cities. Data were taken from these routes to calculate the energy required to be stored by a pure electric bus in each case. These data sets covered a variety of buses and operating conditions and included routes in Sao Paulo in Brazil, Shenzen in China, London and Milton Keynes in the UK and Warsaw in Poland.

By way of illustration, Fig. 2 shows the bus route (No 675-L10) used for the Sao Paulo data gathering. This has a route length of 12 km, carries an average of 56.7 passengers per bus and operates over an elevation profile as shown in Fig. 3.

The London bus route used in the study was the 159 from Marble Arch to Streatham, which is a 10 min frequency service viewed as a typical, but demanding, pattern for operating conditions in London. This route achieved fame in 2005 for being the last route in London running the famous classic Routemaster bus. The Shenzen route (No. 202) at 38 km and with 93 bus stops, is longer than those in the other cities. The No 7 route in Milton Keynes is 24 km long, one of the town's longest urban routes.

From these operational data it was possible to calculate the energy requirements for a full 16–18 h working day and the battery size needed. The results are shown in Table 1.

With EV battery packs costing around £500 per kWh (Element Energy, 2012), large battery packs represent a substantial cost item. Battery size is thus crucial to both technical performance and economic viability. The Milton Keynes case of a medium-length route and relatively low frequency (15 min) produced the lowest power requirement, but even then it needed 5 tonnes of batteries. The alternative would be (as has been done elsewhere) to have a smaller battery but increase the fleet of buses to allow for recharging time. Either way would make the use of battery-electric buses significantly more expensive than using diesel vehicles (or even relatively expensive hybrids).

3. Technical, operational and business design criteria

Most studies to date on electric buses (and EVs in general) have concentrated on the technical design for low carbon vehicles with often superficial consideration of the institutional context and practices in which these technologies need to operate. The work behind the design of the Milton Keynes electric bus project has therefore sought a viable technical solution that reflects an understanding of:

1. The need to reduce battery size, so cutting the additional capital costs to a level that means the overall lifetime costs are comparable (or less) than for a diesel bus;

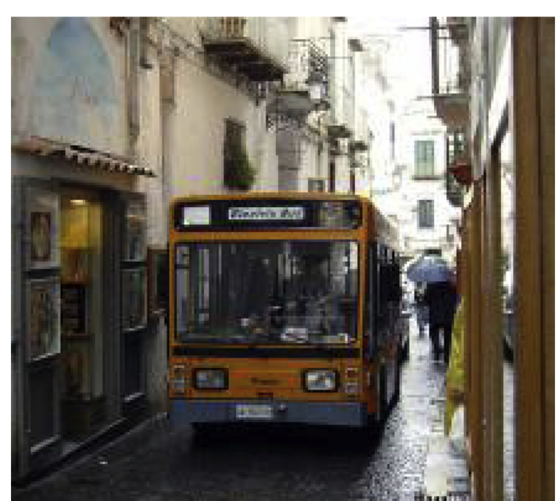

Fig. 1. Small battery-electric bus on a short route in Amalfi town centre in Italy.