Urban Rail Transit (2015) 1(2):71–77
DOI 10.1007/s40864-015-0014-9
http://www.urt.cn/

ORIGINAL RESEARCH PAPERS

The Circumvention of Barriers to Urban Rail Energy Efficiency

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Received: 9 March 2015 / Revised: 17 May 2015 / Accepted: 26 May 2015 / Published online: 18 August 2015

Abstract As energy prices rise, urban rail energy efficiency becomes even more important. Many technological, operational and policy-based energy efficiency measures are well known and can have a notable positive effect on the urban rail systems. However, these measures can remain unimplemented. This lack of action can often be attributed to a variety of conflicting stakeholder opinions and a lack of knowledge transfer. This paper firstly focusses on the energy efficiency requirements of various stakeholders, before discussing about how such conflicts can be circumvented to ensure the success of future energy efficiency projects.

Keywords Mobility · Urban rail systems · Energy efficiency · Requirements · Barriers · Solutions

1 Introduction

Improving energy efficiency is an important goal for all transport systems worldwide, particularly urban transport systems, given the forecasted rise in urbanisation and car ownership [1, 2]. Urban areas currently contain approximately 50 % of the global population, which is expected to rise to 70 % by 2050, leading to a tripling of the travel-km in urban areas [3]. Therefore, it is vital that urban transport systems adapt their entire operations to address these challenges and prevent negative economic, social and environmental consequences.

The importance of urban rail systems—specifically their superior capacity and energy efficiency—should be exploited further in order to achieve these goals. However, despite their high level of energy efficiency, urban rail systems nevertheless consume huge amounts of energy. For example, the London underground consumes over 1.2 TWh of energy annually, which currently costs almost £100 million, and is expected to rise to £140 million by 2020 [4].

Research by the European Commission highlights that the greatest potential for energy savings lies in buildings, whilst the second greatest lies in transport [5]. Given that the urban rail systems consist of a mixture of both (the traction:non-traction split for the two largest urban rail systems in the UK is approximately 75:25), there is great scope to exploit this savings potential and further enhance their efficiency levels [6]. However, it is difficult to implement many energy efficiency improvements in urban rail systems which can be attributed to numerous, often interrelating, factors.

Firstly, this paper provides a brief background on the energy efficiency requirements for urban rail systems in Sect. 2. This is followed by a summary of the main problems associated with improving urban rail energy efficiency in Sect. 3. Subsequently, in Sect. 4, the potential solutions to these challenges are discussed and analysed.

2 Background to Energy Efficiency Requirements

Urban rail energy efficiency improvements can largely be split into two separate categories: energy consumption reduction and reduction of energy consumption per unit

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Editor: Baoming Han

Table 1 The main keywords used during the literature search

Topic	Keywords used
Technical energy efficiency solutions	Regenerative braking; energy recovery; energy storage; retrofitting; air conditioning, escalators, lighting; innovative technology*; flywheel
Operational energy efficiency solutions	Peak travel; power peaks; timetable optimisation, service frequency
System characteristics	AC power; DC power; legacy system; rail*; urban rail; metro; tram; light rail
Political issues	Political strength; political will, electoral cycle, funding, legislation, partnerships; tender*; franchis*

* The use of asterisks at the end of keywords means that different suffixes are included in the search

output. Urban rail energy consumption can be reduced through both traction- and non-traction-related measures, although constraining circumstances mean it is one of the numerous trade-offs, also including capacity, safety, journey time, reliability and comfort; the prioritisation of which varies between the systems. Further information on a comprehensive set of 22 energy consumption-related key performance indicators that enable a multilevel analysis of the actual energy performance of the system, an assessment of the potential energy saving strategies and the monitoring of the results of implemented measures is detailed in [7]. Energy efficiency can subsequently be considered as the energy consumption per unit of output (e.g. kWh per passenger-km), and can therefore be improved by increasing the passenger density on the existing rolling stock for a given level of energy consumption through, for example, modal shift. Modal shift is the movement of travellers from private cars to public transport and can greatly increase the energy efficiency of the overall transport sector, while reducing congestion and emissions levels within cities.

Energy efficiency requirements come from numerous stakeholders and can be summarised into three main categories: economic requirements, environmental requirements and political requirements. The economic case for greater energy efficiency is the predominant requirement; less energy used leads to cost savings, increases business competiveness and protects against rising energy prices, which, for example, in the UK, are forecasted to rise by up to 104 % by 2030 [8]. This is attributable to a number of factors, including additional charges on electricity to encourage large-scale renewable energy generation; these currently cost Transport for London an additional £16 million annually [4]. Reducing energy consumption can lower the power peaks within an urban rail system, which can lead to cost savings [9]. From an environmental perspective, energy efficiency allows the reduction of energy consumption, and hence CO_2 and other associated emissions. Finally, from a political perspective, greater energy efficiency can help satisfy numerous political energy efficiency and emission requirements at local, national and international levels, while helping in increasing energy security and reducing dependency on fossil fuels [10].

3 Methodology

This section presents the methodology of the investigation carried out to develop a comprehensive assessment of the barriers to greater urban rail energy efficiency from the available body of research. Urban rail systems are highly complex; energy efficiency improvements can be effected in a plethora of different ways and as such, it was important to find the state-of-the-art energy efficiency solutions and to analyse the barriers to their implementation. This was achieved through a variety of means.

An academic literature search—which constitutes the main reference source for this paper—was primarily conducted using international, online databases such as Scopus (http://www.scopus.com) and the Newcastle University Library search tool, which is linked to the major electronic resources worldwide. The main keywords used in this literature search are shown in Table 1.

Furthermore, relevant unpublished information from dedicated conferences, seminars and workshops was examined. In addition, as the topic is not only of academic interest, the literature search also included international databases of research and industrial projects, such as the transport research portal (http://www.transport-research-portal.net) and Spark (http://www.sparkrail.org). Documents by organisations such as the European Commission, the United Nations and the International Energy Agency were also considered, in addition to press releases and reports from manufacturers and operators.

In general, the literature search was focused on the last 15 years, although older resources were also consulted where their relevance could be determined. In total, over 150 documents and websites were reviewed for the purpose of this paper.

4 Problems

4.1 Uniqueness of Systems

Problematically, urban rail systems are intrinsically unique, with solutions suiting one system often being inappropriate for others. Nevertheless, a range of solutions—both technological and operational—exist that can allow urban rail systems to improve their energy efficiency. However, while these technologies exist, they may remain unimplemented for many reasons, including a lack of capital preventing their purchase/lack of subsidies to enable retrofitting, and a lack of awareness/full understanding of the technology. Most urban rail systems use direct current (DC) traction, via a catenary or third rail, with examples of AC traction being a relatively new phenomenon (i.e. S-Bahn Systems in Germany, Delhi Metro). DC systems are commonly used for small, dense rail networks with many trains as transformers and rectifiers are lineside rather than on-board, enabling lightweight rolling stock compared to AC systems, where such equipment is located onboard. However, AC systems exhibit lower losses in the power supply system (due to higher voltages) and are able to recover regenerative braking energy much simpler than in DC systems. As such, different strategies need to be applied. Further technologies to aid energy efficiency improvements in urban rail systems include energy-efficient driving, reducing power supply losses, lightweighting rolling stock, improving the energy efficiency of HVAC/lighting and those that lower the energy consumed whilst stabled. For a more comprehensive look at such measures, see [11, 12].

4.2 Awareness and Understanding of Technologies

It is also important that appropriate guidance is given to those in decision-making positions to ensure that new technologies are implemented appropriately; this was notably not the case in Ottawa, Canada, whereby the publicly owned urban transport service (OC Transpo) purchased 177 hybrid buses in the belief that they would produce the stated achievable fuel savings when operated in any manner [13]. Many of these buses were then operated on long expressways, with minimal braking and accelerations where the benefits of the hybrid engine were exploited very little and fuel consumption was notably greater than comparable journeys in diesel-powered buses [13]. A retrofit programme to then convert all these to diesel-powered engines was then implemented, expecting to cost over £7 million, proving extremely wasteful and time consuming, simply because insufficient guidance was given to those in charge of procurement. It can also be more difficult to make decision-makers aware of the current situation; in, for example, certain legacy urban rail systems, it has been found that there is a lack of accurate knowledge on the energy flows within the system itself, which can obstruct efforts to implement energy efficiency measures [6]. However, in certain cases, the modelled energy savings have actually been inferior to the energy savings achieved in real measurements of the system; it was reported that in Bielefeld, Germany, energy savings from a newly installed flywheel delivered annual savings of 360 MWh—63 % greater than the expected 220 MWh [14].

4.3 Lack of Exploitation of Energy Savings from Existing Vehicles/Infrastructure

It appears that, in certain cases, there is insufficient impetus from governments to facilitate energy efficiency improvements; both through the aforementioned lack of funding mechanisms, and the lack of legislation requiring improvements in energy efficiency, particularly in the case of existing assets. Necessitating such energy efficiency improvements is very important for urban rail systems; given the 30–60-year working life of rolling stock, many vehicles currently in use in light rail, tram and metro systems will still be in service for decades [15]. However, current energy efficiency directives fail to place sufficient emphasis on increasing the energy efficiency in the existing infrastructure, rolling stock and equipment. It is widely acknowledged that the greatest energy savings can come from the existing buildings and transport yet, until 2012, the only legislation to instigate such actions was voluntary [16]. More recent legislation has failed to properly address this, which appears to be due to inappropriate implementation, and the weakening of requirements throughout the legislative process. This can be attributed to a lack of both political will and a sufficient understanding of the urban rail systems [16, 17]. However, there are significant costs associated with the retrofitting energy efficiency technologies to the existing rolling stock; where the new technology is not replacing the existing technology at the end of its life, often the energy/cost savings are insufficient to allow the new technology to deliver benefits during the remaining life of the rolling stock. Additional funding mechanisms may be required, given the scale of the energy savings delivered.

4.4 Effects on Service Quality

Certain energy efficiency measures can detract from the quality of service, which can dissuade customers to continue using the system [18]. Such measures include switching off escalators during off-peak times, forcing passengers to walk up them, lowering the use of air conditioning during summer months, resulting in uncomfortable climatic conditions, reducing the frequency of service, increasing average waiting times and operating smaller trains off-peak, potentially leading to cramped conditions. Furthermore, construction, repair and upgrading work carried out on urban rail systems can also negatively affect the passengers, despite the outcome leading to a higher quality system (e.g. the time required to replace old, inefficient escalators). Friman [19] describes how passenger opinions of the PT system quality declined in the face of such improvements, due to the level of disruption caused during their implementation.

4.5 Political Issues

It is also vital to develop methods to circumvent the current prioritisation of short-term economic issues over long-term environmental and economic sustainability. This involves addressing the numerous political distractions, including the highly disruptive effects of political campaign cycles and the need to curry favour with voters to aid re-election, at the expense of the implementation of potentially controversial projects. The political campaign cycles can be numerous; for example, in London, there are general, mayoral and borough elections, each taking place every 4–5 years, which is significantly shorter than the timescales for planning/funding that rail systems often work on. A notable example of the problems caused by the political cycle is the London congestion charge, which was viewed by many as an extra tax that brought no benefits. The scheme (and especially the important 2006 Kensington and Chelsea extension) became a political issue during the 2008 mayoral elections, which led to the conservative opposition candidate, Boris Johnson, to state he would remove the charge in the Kensington and Chelsea area if was voted into power, which he achieved [20].

5 Discussion of Solutions

5.1 Shifting Peak Travel to Facilitate Modal Shift

When attempting to utilise urban rail systems to encourage modal shift, it should be ensured that sufficient capacity exists, or can be made to exist. During peak times in, for example, London this may not be possible without additional capacity improvements/mobility management solutions. Singapore has demonstrated success in using soft measures to move travellers out of peak time operations; the Singapore Land Transport Authority introduced a 2-year trial scheme in 2013 to provide free travel for those passengers who end their journey at one of the 18 central metro stations before 07.45 on weekdays, with discounted travel for those exiting between 07:45 and 08:00 [21]. This benefits the passengers through cost and time savings, and a more pleasant ride, and resulted in a permanent moving of approximately 7 % of the peak-time ridership (between 08:00 and 09:00) to the pre-peak (07:00–8:00). It was found that over 66 % of those who stated that they did not switch had set times when they must be at work [21].

However, notable levels of modal shift are very difficult to be achieved on a long-term basis, due to the numerous societal and political challenges. These are discussed further by Batty et al. [22], who analyse how best to attract people to public transport and dissuade car usage using ‘push’ and ‘pull’ mechanisms. This highlights the necessity for significant improvements in the public transport system as a whole, in terms of quality, capacity and level of integration, to help remove the perception that public transport is unclean, unreliable and of low comfort [23–25].

5.2 Innovative solutions

Problematically, urban rail systems are often very unique in their design, and so prescribing solutions suitable for all or most systems is rarely effective. This necessitates decision-makers to work with all the relevant stakeholders to develop innovative solutions specific to the system in question, in all areas of the system from finance mechanisms to technological measures. Research also highlights that the public react positively toward energy-saving measures that they perceive to be clever or innovative; for example, floor tiles containing piezoelectric mats that produce energy when stepped upon have been installed in busy locations worldwide, with a positive reaction from the public [26]. This suggests that the way in which energy efficiency and energy-saving schemes are marketed can help determine their level of social acceptance.

Innovative funding solutions should also be investigated, which can provide the required capital to fund the implementation of energy efficiency measures. For instance, Southeastern Pennsylvania Transportation Authority (SEPTA) of Philadelphia sold 250,000 3-day passes to the international deal website Groupon for $1.8 million, with the aim of encouraging more people to try its PT services and become more open to engaging in future modal shift [27]. The £1 billion funding for the Northern Line extension to the London underground was also considered to be an innovative method of funding; with the entire project being funded with the intention of no detriment to the British taxpayer. This involved the Greater London Authority borrowing the £1 billion, with a repayment guarantee provided by the UK Government to minimise borrowing costs [28]. The loan repayments are then to be made through contributions from local developers (to be collected by the local authorities) and through the growth in business rates revenue within the enterprise zone in which the extension is to be built. Over time these funding sources are expected to cover the complete repayment of the loan [28]. However, the transferability of the model to dissimilar cities is less clear, as it is only the soaring demand for property and high land values that are considered to have made the scheme feasible in London [29].

While innovative technologies exist that could lead to a notable impact in energy consumption reduction, a lack of certainty regarding their operation and ease of implementation can dissuade operators from implementing them. This demonstrates the needs for governments to encourage the development of collaborations between original equipment manufacturers and end-users to allow for demonstration projects of technologies to facilitate their market uptake by developing a business case for them. For example [14] highlight how energy-saving technologies can be made financially viable using the economies of scale principle, with several operators working together; committed investment from each operator, and a standard design for an energy storage system (ESS) would allow the cost to each operator to be significantly reduced. Similarly, the use of flywheels for on-board ESSs is becoming a more widely investigated topic, but a prototype, developed in Rotterdam for their tram system, caused significant damage when it became detached from the tram during testing in the workshop. However, new, safer composite flywheels are in development, and the DDFlyTrain flywheel program is of particular note, which involves a UK Government-funded collaborative effort between a flywheel developer (Ricardo), a hydraulic transmission developer (Artemis Intelligent Power) and Bombardier.

Other types of innovative partnerships between stakeholders have also led to fruition; in 2010, the SEPTA—the public transport operator for Philadelphia—aimed to further increase the energy efficiency of their network operations by further utilising the regenerative braking capabilities of their rolling stock in their metro system. The plan involved linking the third rail system to a wayside ESS, thereby allowing excess regenerated energy to be stored and used at a later time rather than wasted in rheostats when no other rail vehicles are in the same electrical section [30]. However, while this plan would successfully save large amounts of energy, it could not be made economically viable in its proposed form. Therefore, after dialogue between numerous stakeholders, a collaborative, profitable plan was developed to use the ESS for multiple purposes, such as voltage stabilisation and peak shaving on the external electrical grid [31]. The success of this plan is centred around the money generated from participating in the local electricity market, which is 3–4 times greater than the value of the energy savings themselves, and equates to approximately $200,000 per annum [32].

The initial investment came from each involved party: Envitech Energy (Power controls and power conversion systems), Viridity Energy (Smart Grid Technology) and Saft Batteries (Lithium-Ion battery), each of them invested its own funds in the project to provide the necessary capital to install the proposed infrastructure [30]. Funding was also provided through the Transit Investment for Greenhouse Gas and Energy Reduction programme. Indeed, this scheme proved so successful that a second, hybrid ESS will be installed on the same line, consisting of both a supercapacitor and a battery [33].

However, the transferability of such projects should be considered thoroughly before implementation; preliminary testing of the ESS in Philadelphia demonstrated that the revenue from the frequency generation market was strongly influenced by the external climatic conditions in the region, with the revenue generation in the coldest month (January—average daily temperature 0 °C) being six times that of the warmer months [32]. This is in stark contrast to other, more conventional, schemes, where energy recovery was highest in the summer months, due to the higher auxiliary energy consumption in the winter months [14].

5.3 Solutions the Public Do Not Notice

The travelling public are much more likely to accept energy efficiency measures that do not negatively affect their travel experience and as such, maximising the level of energy recuperated from the regenerative braking of urban rail rolling stock appears to be a promising solution. Combining regenerative braking, storage and reuse with basic timetable optimisation can lower energy consumption by up to 45 %, depending on the individual characteristics of the system in question [11]. However, it is important that due consideration should be given to the side-effects of the chosen ESSs, particularly larger, wayside ESSs; for example, the noise produced by flywheel ESSs during normal operation can be as high as 96 dB and as such their effects on the surrounding environment should be taken into account [14].

Other solutions include energy-efficient driving, aided through the use of driver advisory systems or automatic train operation, which can reduce or remove the negative effects of inefficient driving styles. However, drivers do not always utilise the guidance available to them appropriately, a challenge which was circumvented in the Helsinki tram system by training all staff in public transport, energy and environmental issues, so as to help motivate drivers and other staff to take practical actions for the environment, a scheme which proved to be successful.

5.4 Political Strength

Political strength and support is critical to the successful implementation of numerous energy efficiency measures. Politicians are responsible for defining laws, engaging stakeholders and developing funding mechanisms. For example, politicians should further facilitate dialogue between relevant stakeholders (i.e. industry, operators, research institutes) to share expertise and help develop successful urban rail energy efficiency solutions; it is prohibitively costly to address the problems the transport sector faces individually; addressing problems as part of a connected approach across modes is vital for success. This should also include the development of funding mechanisms to support the whole process, helping in bridging the gap between research and testing of energy efficiency-related technologies in universities, and the final technologies developed and sold by private companies.

Longer-term energy efficiency projects, especially those requiring high levels of investment, may need a cross-party consensus to ensure their continued implementation in the face of a change in government. In this sense, there is a great need to be able to ensure the incumbent politicians continue to spend public money, potentially in the face of public criticism, when the benefits may only manifest in a number of years, when future MPs may take the credit.

The numerous advantages of driverless trains over conventionally driven trains include the ability to program their operation to maximise their energy efficiency, to operate regardless of time of day without the need for expensive personnel, and their equal (or even superior) safety record [34, 35]. However, the process of introducing driverless trains is commonly stagnated or stopped by drivers' unions. The notable current exception is the Paris Metro System, where Ligne 1 was converted to fully driverless operation after 10 years of preparation and consultation with unions. It is recommended that politicians take a firm stand on such matters to ensure that, where necessary, driverless operations can be implemented.

To circumvent the issues regarding the political cycle, and to provide MPs decision-makers with confidence, it could be legislated that all recommendations from panels of experts (e.g. the UK committee for climate change) should be compulsory to implement, ensuring necessary energy efficiency legislation is implemented. Additionally, a greater usage of passenger advisory bodies to predetermine the effectiveness and acceptability of policies would also ensure that a more accurate understanding of the opinions of passengers is developed. However, this may not account for those people initially against a certain measure or programme, but who could, over time, adapt and accept it.

5.5 Competitive Tendering

Although sometimes considered a contentious topic, placing the operations of urban rail systems out to tender can lead to significant benefits. Tendering can instigate private sector investment and encourage innovative working practices, which can relate to energy efficiency. Private investors hold public transport in high regard, due to its demonstrable strengths, such as its stable revenue and cash flow, the clear potential for growth and its status as a provider of essential services. However, the potential negative consequences of tendering should also be considered, such as concession/franchise failure, contract rigidity scuppering innovation and the costs of the tendering process for bidding companies. Nevertheless, tendering the operation of the system can increase the competitiveness of the bids and, if not undertaken previously, can provide the local authority with a better understanding of the costs required to run the system at the increased level of efficiency [36]. However, research undertaken by ERRAC and the UITP found that 17 % of the urban rail systems in Europe are operated without a public service contract, and of the remaining 83 %, only 17 % of those contracts were awarded after having been put out to tender, the rest being directly awarded [37]. Therefore, the possibility to tender operations of urban rail systems should be explored to a greater extent in the future, although compulsory tendering of operations has been postponed by MEPs during the weakening of the revision to the Public Service Obligation Regulation 1370/2007 [38]. It should also be noted that impetus can be given to the concessionaire/franchisee to improve the energy efficiency of the system; if they are not paying for the energy consumed, there may exist little incentive to develop energy efficiency measures. However, this is only practical where a sufficient understanding of energy flows in the system is already known.

6 Conclusion

The need for greater energy efficiency has been gaining in prominence for many decades, spurred on by rising energy prices and advances in technology. While urban rail is perhaps the superior mass transit system, the energy consumption in many systems is still able to be reduced significantly. This paper has aimed to summarise the current challenges in developing greater urban rail energy efficiency, and has discussed a range of solutions that appear to be applicable to other urban rail systems.

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