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E-bikes and urban transportation: emerging issues and unresolved questions

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Abstract A range of factors, including improvements in battery and motor technology coupled with innovative industrial design, are contributing to the emergence of electric bicycles (E-bikes) with greater range and enhanced performance. This paper examines this emerging vehicle type within the context of sustainable transport. Mobility, safety and environmental impacts are considered. While governments could employ a range of policy instruments to respond to the opportunities and threats presented by these vehicles, the primary focus internationally is on vehicle standards. A review of regulations in different countries highlights little consistency in the parameters used to regulate E-bikes. Unresolved issues are identified to guide future research on this vehicle type.

Keywords Bicycle transportation · Electric power assisted bicycles · Regulations · Health and safety

Introduction

Cities throughout the world are grappling with the challenge of improving the sustainability of their transportation systems which have developed to be heavily dependent on the private motor vehicle. Those same cities face the added challenge of catering for the mobility needs of an ageing population, many of whom have become accustomed to the independent mobility provided by the car. Beyond the mobility needs of that older cohort, there are added issues of health and wellbeing for which maintenance of physical activity is increasingly seen as a critically important.

The bicycle has the potential to play an important role in addressing the problems outlined above. However, the performance of the bicycle depends on the physical ability of the rider and the rider's willingness to provide all the energy needed to reach their destination. The provision of power assistance to the rider therefore has the potential to

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expand the role of the bicycle in urban transport. Consumers are being presented with an increasing range of electric bicycles, referred to generically as E-bikes. This emerging category of vehicle has not been examined in detail from a transportation perspective.

The aims of this paper are to:

- Present a conceptual model for framing the examination of E-bikes in the context of sustainable urban transport,
- Draw insight from the literature to illuminate components of the model including emerging trends in E-bike technology, the range of impacts associated with their use, the regulatory approaches being taken to manage this class of vehicle along with market responses to those regulations, and
- Identify emerging issues of relevance to transportation planning and policy which could provide a focus for future research.

The paper begins by presenting the conceptual model used to frame the examination of this emerging vehicle type. E-bike technology is then reviewed. Subsequent sections examine a range of issues including the market size and mobility implications along with environmental, health and safety impacts of E-bikes and the approaches taken around the world to regulate this type of vehicle. The final section presents the conclusions of the paper and highlights unresolved issues which serve as a guide for future research efforts directed at this class of vehicle.

A conceptual model for framing the examination of E-bikes

The conceptual model shown in Fig. 1 reflects the essential elements of Manheim's seminal 'Transportation Systems Analysis' model (Manheim 1979) in which the activity system (A) and technology (T) interact through equilibration of demand and supply to produce flows on the network and ultimately a range of impacts.

Consistent with the travel behaviour literature (Ben-Akiva et al. 1996) a distinction is made between mobility decisions (specifically individual/household vehicle ownership decisions including the decision to purchase an E-bike) and travel decisions (individual trip level decisions covering frequency, timing, mode, destination and route). Mobility decisions are long-term choices. In contrast, travel decisions are made on a short-term time frame and they are conditional on vehicle purchase decisions and vehicle availability. The user choices result in a level of use, or exposure, for E-bikes and consequently a range of mobility, environmental and health/safety impacts. Depending on the alignment between those impacts and government transport policy objectives there may be a case for policy intervention. In the context of E-bikes, relevant policy objectives could include:

- Improving transport system efficiency,
- Improving safety,
- Reducing use of non-renewable energy,
- Reducing environmental impacts,
- Maximising accessibility and mobility benefits.

A variety of policy instruments are available which have the potential to influence either the activity or technology dimensions of the system, and thereby bring the impacts into line with desired policy objectives. Both local and international government policy interventions have the potential to produce a profound effect on the system. It could be argued for example, that Chinese government decisions to ban or restrict internal combustion engine

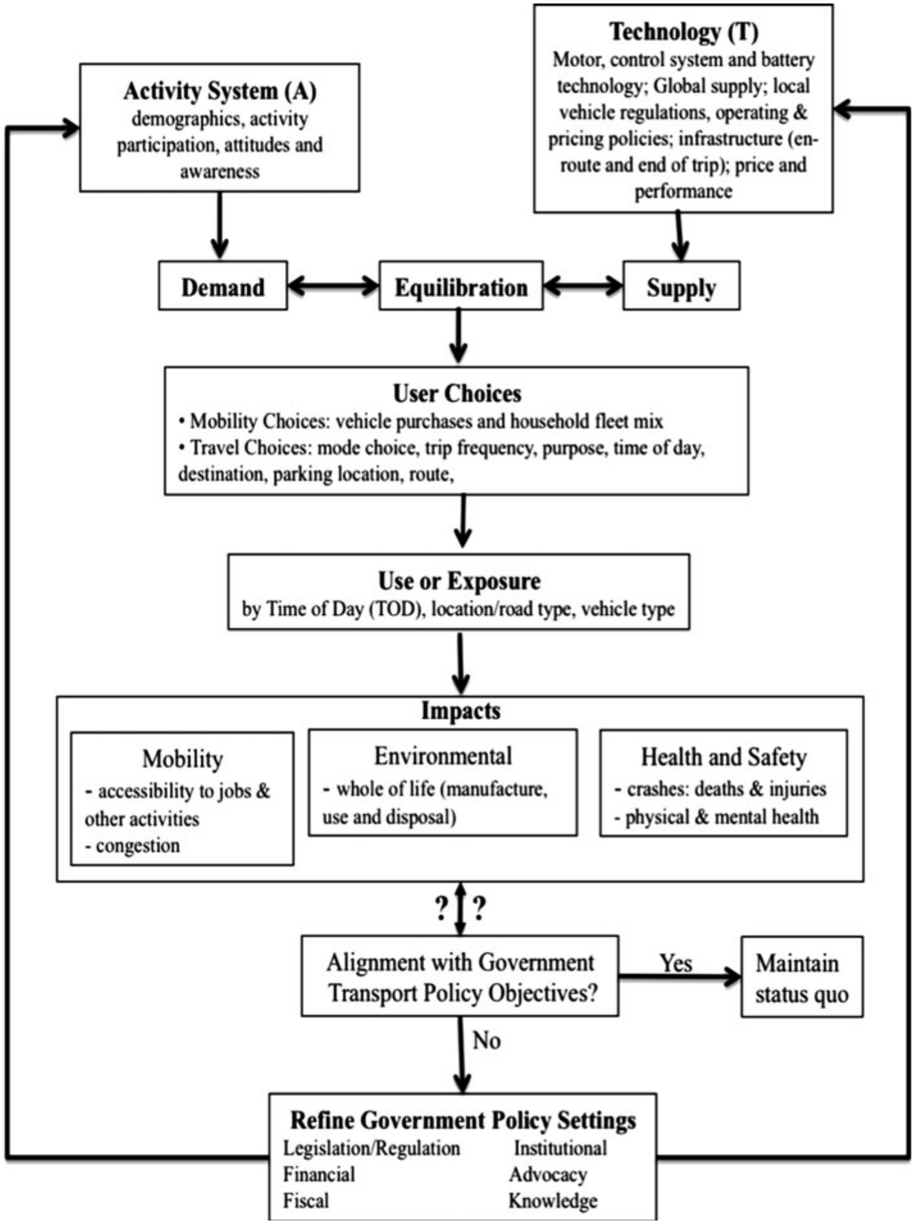

Fig. 1 Conceptual model

(ICE) motor scooters (Cherry 2007) has not only driven demand for E-bikes in China but has also been a stimulus to the expanded range of E-bikes available in the world market.

The following sections draw insight from the literature to illuminate components of the model shown in Fig. 1. Attention is first turned to exploring the technology dimension before considering the demand, use and impact dimensions.

E-bike technology

The nature of E-bike technology is of fundamental importance in the supply side of the conceptual model (Fig. 1). Local vehicle regulations will govern what E-bike technology from the global supply is available in individual jurisdictions. When examining E-bike technology, it is important to begin by distinguishing between powered bicycles (PBs) and power assisted bicycles (PABs). On PBs, the engine or motor operates with a switch or throttle and so provides power assistance without any pedal action. In contrast, on PABs the power assistance is only provided when the rider is pedaling.

PABs have been in existence since the beginning of last century when the *Singer Company* in Britain began manufacturing motorized back wheels, powered by a small two-stroke engine, that could be fitted to existing heavy-duty bicycle frames (Parker 1999, 2002). As a result of improvements in battery and motor technology, along with concerns over emissions from two stroke IC engines (particularly in China), the vast majority of innovation in this vehicle class today relates to E-bikes. The modern E-bike, originated in Japan in the early 1980s, where the focus seems to have been on making cycling easier for the elderly (Parker 1999). Both E-PABs and E-PBs are available round the world today. E-PABs are also referred to either as Pedelecs, a new type of hybrid or as ‘light electric vehicles’.

E-Bike components can be split into four main groups: bike parts, motors, electrics and batteries. All of these components have been the focus of a great deal of research and development in their own right and as they apply to E-bikes.

The power assistance is commonly provided through either a hub motor (front or rear) or through direct drive to the chain near the crank. There can be a torque sensor built into the cranks which results in higher power assistance being provided when the rider is working the hardest (e.g. standing start or riding uphill). The controls on some models allow the user to turn off assistance all together or to vary the power assistance level. Some hub motor models include a regenerative energy feature to put power back into the battery either under braking or when traveling downhill. The current regenerative systems appear to add energy back to the battery at the margin under anything which could be considered to be usual riding conditions. For example, riders might expect 10–15% of the energy drawn from the battery when climbing a hill to be returned on a comparable downhill run (AtoB 2010). They can also add to the drag in the motor (compared to models with no regenerative function) which can have the advantage of moderating speed on downhills but brings with it the disadvantage of harder pedaling once the battery is flat.

For E-bikes, battery technology has presented the biggest technical hurdle. Batteries have two main impacts on the E-Bike’s ease of use: they add to the weight of the vehicle and their energy capacity places a cap on the distance over which the motor can provide assistance. These factors are inextricably linked. More energy storage makes it possible to ride a longer distance, or climb more elevation when traveling under power assistance. Therefore it would be desirable to have as much battery capacity as possible but that adds to the vehicle’s weight. Increased weight has three major effects. First, a heavier vehicle requires more power to propel it and so there is a higher drain on the battery. Second, it makes the bicycle far more difficult to handle when not under power. This is relevant when being ridden, since the rider has to exert much more effort to propel a heavier E-Bike once the battery is flat. The additional weight is also an issue when lifting them onto bike racks or manoeuvring them in and out of storage. Finally the added weight increases the inertia of the bike when in use and can therefore add to the property damage or injuries which result in the case of a crash. Thus it is necessary to find a compromise between the weight and the storage capacity.

The majority of early E-Bikes and home fit kits came standard with a Sealed Lead-Acid (SLA) battery. These batteries are cheap and reliable and have a relatively long life, but have the major drawback of having the lowest energy density (30 Wh/kg) of all rechargeable batteries. This has meant that the range of most E-Bikes is limited to 20–30 kms per charge while around 10–12 kg (30–40%) of their weight (or more on some models) is the battery.

Lithium Ion (Li-ion) batteries are currently the most promising energy storage system, their only drawback being their higher cost (3–4 times more than SLA). These batteries have a similar life span to that of SLA, provide better performance and have an energy density of 140 Wh/kg, meaning that they can provide the same range as current SLA batteries at about 20% of the weight. Ulrich (2005) has undertaken research into the trade-offs between cost, mass and range for personal electric vehicles. In relation to E-bikes, Ulrich estimates an increase in retail price of about $US 38 for each kilogram reduction in vehicle mass (primarily a function of battery technology).

The component technologies described above are then used by manufacturers to produce a range of E-bike designs. E-bikes are available in a range of models and styles, as illustrated in Fig. 2. Most are obvious variants of a conventional bicycle while some, such as those in the lower panels of Fig. 2, are styled more like a motor scooter than a bicycle.

Fig. 2 Power assisted bicycles (*Image sources* www.evehicle.com.au, www.cyclelicio.us, www.kalkhoffusa.com, www.nycewheels.com)

Beyond the vehicles that have a similar appearance to a bicycle, there is a variant where the body has diverged from the traditional bicycle frame to be more akin to an enclosed vehicle. This class of vehicle is not new with an example of historical significance, the Sinclair C5 having a short life in the mid 1980s. The Sinclair C5 was a power assisted, open top, pedal trike with a 250 W motor. Sales of the C5 were slow and the manufacturing operation closed about 6 months after the vehicle was launched in the UK. More recent examples of enclosed light electric vehicles include the Twike (Fig. 3a), and the Aerorider (Fig. 3b), which have paid greater attention to aerodynamics in the body design and provide full weather protection for the rider. The Aerorider is currently available as a human powered velomobile with an electric hybrid under development. While the Sinclair C5 and the Aerorider are single occupant vehicles, the Twike can carry two occupants sitting in tandem.

Alternative designs for powered, two-wheel devices have also emerged. In 2002 the Segway Human Transporter (Fig. 4) was first offered for sale in the USA and similar self balancing devices have emerged in China (e.g. Rijaing Segway styled device). These battery powered, self-balancing personal transportation devices do not require the rider to pedal.

In contrast to the self balancing devices, light electric vehicles are emerging (Fig. 5) which are similar in design to a bicycle, but require no pedaling. Volkswagen recently launched Bik.e (Fig. 5a) a folding electric vehicle with a range of 20 km and a top speed of 20 kph (Hanlon 2010). While radically different in design, the Yike (Fig. 5b), is a folding fully electric vehicle with a range of 10 km at a top speed of 25 kph.

The precise nature of the regulations in any jurisdiction will determine which, if any, of the vehicles described in this section are classified as ‘bicycles’ or ‘E-bikes’. The nature of those regulations will be discussed shortly.

Market size, demand determinants and mobility implications

Attention now shifts to the demand side of the conceptual model shown in Fig. 1. There is little knowledge about the determinants of individual decisions to purchase an E-bike and considerable uncertainty about the aggregate market size. Caution is needed when interpreting information on the worldwide E-bike market which is prepared for, and released by, the industry. Volschenk (2010) reports market estimates prepared for the European Two-wheeler Retailer’s Association suggesting that global E-bike sales will be on the order of 24 million units in 2010 with about 90% of them sold in China and a further 5% sold in the remainder of Asia (India, Japan, Taiwan and South-east Asia). The continuing

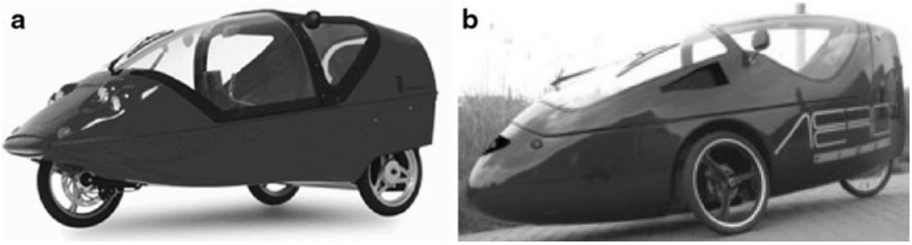

Fig. 3 Three wheel E-bike variants. **a** Twike (*Image source* www.twike.com), **b** Aerorider (*Image source* www.aerorider.com/en/aerorider.html)

Fig. 4 Segway personal mobility device

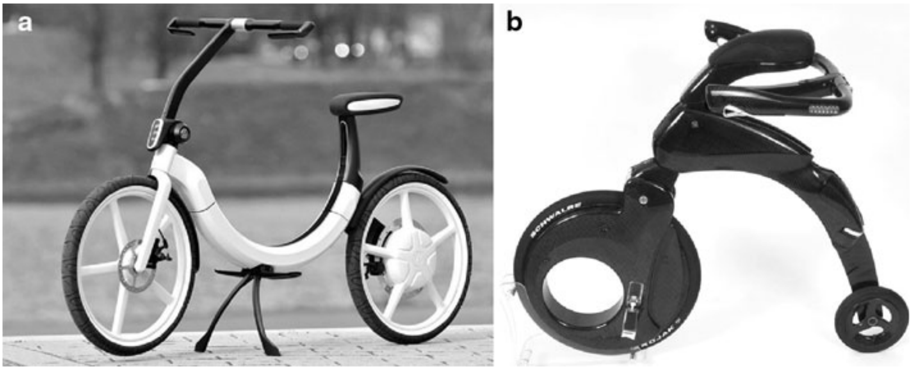

Fig. 5 Innovative light electric vehicle designs. **a** Volkswagen Bik.e (*Image source* www.blogs.zdnet.com/gadgetreviews/?p=14277), **b** Yike (*Image source* www.yikebike.com/)

high sales in China are attributed to government bans on petrol engine mopeds and scooters leaving little choice for consumers who are looking for a moderately priced motorized mobility option but to turn to an E-bike. The European market is dominated by the Netherlands and Germany which account for about half the E-bike sales in the EU. Sales in those countries in 2009 were reportedly of a similar order of magnitude to annual US sales (Holland, 210,000 units, Germany, 140,000 units and the USA 150,000 units[1]). Goodman (2009), writing in the New York Times, reported that one-third of the money spent on bicycles in the Netherlands in 2009 was spent on electric-powered models. In the US context, sales growth may be stimulated by the release of E-bike models by two major US

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[1] Off the record comments from some retailers in the USA suggest the actual figure there could be an order of magnitude smaller.

manufactures (Giant and Trek) and the entry of one major consumer electrics retailer (Best Buys) into the light electric vehicle market in America.

The example of the Sinclair C5 discussed earlier highlights that not all vehicles in this class will generate sufficient market appeal to produce commercial success. Technology diffusion is often characterized as following a somewhat predictable transition as the market grows from innovators, to early adopters to the early majority, to the late majority and finally to the laggards (Rogers 1962). Moore (2006) conceptualized that a chasm exists in the early adopter market which can be difficult for some products to cross. In that regard, the Segway could well be an example of a product which appears to be struggling to cross that chasm meaning that wide spread uptake is not guaranteed. The same uncertainly exists about the uptake of E-bike technology and its variants.

While growing E-bike sales are reported in China, Japan, the USA, and Europe (Parker 2004; Vandore 2008; Weinert et al. 2008), the literature provides little insight into the factors contributing to that growth. Higher fuel prices have been cited as motivation to switch to these vehicles for commuting (Vandore 2008).

Few studies have sought to explore the potential role of E-bikes as an urban mobility option. The largest electric bicycle study to date was undertaken in 2000 by the Centre for Electric Vehicle Experimentation in Quebec (CEVEQ). That study found that the bicycles tested could ‘meet the needs of a clientele of moderately physically active working people travelling a distance of less than 20 km, but were not suited to the needs of a clientele of regular cyclists because their speed limit was restricted to 24 km/h’ (Lamy 2001). Evaluation of CEVEQ’s field trial found that nearly two-thirds (64%) of the 369 Quebec participants said they were prepared to use E-bikes as a mode of commuter transport. Of those who usually travelled by car, the percentage was marginally higher at 65%, while for bicycle users, the rate was 71%. These results suggest the project participants were attracted to the technology and the benefits they perceived it provided for utilitarian travel, particularly commuting.

Parker (2003, 2006) argues that E-bikes present a mobility option for the elderly and those with a physical impairment who are unable, or find it uncomfortable, to ride a conventional bicycle. E-bikes have potential to appeal to individuals who would otherwise not ride, or to increase the frequency or range of riding for those who are already using a bicycle for some trips. In Japan, nearly three-quarters of purchasers have been reported to be women while about two-thirds of all purchasers were over 50 years of age (Parker 2004). Parker (2004) also notes smaller markets (of about 10% each) for women under 40, who may have been attracted with the assistance of the vehicle when carrying a young child and shopping, and 40–50 year old men. The latter group was perceived to value the time saved moving around congested central business districts but wished to reduce their effort so they would not work up a sweat and also because they found the E-PAB easier and more convenient to use and park than a car.

Cherry and Cervero (2007) studied the characteristics and mode choice behaviour of electric bicycle users in two large Chinese cities: Kunming and Shanghai. Their analysis revealed that electric bike users had higher daily vehicle kilometers travelled (VKT) than bicycle users. In those two Chinese cities, electric bikes acted as less of a transitional mode between human-powered bikes and the car, and rather as a more affordable, higher quality mobility alternative to public transport (specifically buses). While less marked than in the results from Japan discussed earlier, Cherry and Cervero did find a difference in usage by gender with men, across all age categories, generally less likely to opt for electric bikes than women.

Impacts arising from E-bike use

Mobility impacts

The absence of detailed data means that the relative advantages and potential markets for this type of vehicle remain unclear. Their appeal to women is potentially very important given that women are under-represented as cyclists in many countries (Garrard 2003; Edmond et al. 2009). The mobility benefits of E-bikes can relate to the reduced effort required to ride or the greater range which is possible. Where an E-bike's use substitutes for a motor vehicle trip, there is the potential for benefits in terms of easing congestion, reducing emissions and reducing consumption of non-renewable resources. E-bikes may reduce the constraint that lack of end of trip facilities, specifically showers, can have on people switching to commute by bicycle (Rose and Marfurt 2007). Improvements in on- and off-road bicycle facilities designed to encourage greater use of conventional bicycles may be a pre-requisite before E-bike use could be expected to grow. There is the potential for growth in E-Bikes use to discourage pedestrian and bicyclist activity in much the same manner as could increased use of the Segway and motorised mobility scooters.

There is no evidence of E-bikes completely replacing conventional bicycles. For older riders, either due to declining physical capacity with age, or ill health (e.g. arthritis) the assistance provided by the motor could be of fundamental importance in determining whether the trip is feasible or not by bicycle. There could be a niche market related to E-bikes providing an access/egress mode for public transport. Research in the USA (Innovative Mobility Research, undated) examined the potential for low speed modes (bicycles, electric bikes and Segway Human Transporters) to cater for commuting from suburban railway stations to local area businesses. This is often referred to as the 'last mile challenge' of increasing transit ridership. Shaheen et al. (2010) argue that E-bikes could be a feature of the next generation of city bikesharing schemes which would have a greater mulit-modal focus. One tangible example of that scenario is the two E-bike parking and recharging facilities, each with a capacity for 100 E-bikes, which have been installed adjacent to railway stations in Tokyo (Sanyo 2010).

It is clear that there is limited reliable information on the market for E-bikes and little understanding of how these vehicles impact the mobility and travel decisions of individuals or households. Additional research into the drivers of demand and current usage patters, particularly the extent of utilitarian use, would help to enhance understanding of the role the vehicles currently play, or could play in the future, in the context of urban travel.

Environmental impacts

A detailed assessment of the environmental impacts associated with E-bikes requires a whole of life analysis covering manufacture, use and disposal. The existing literature provides limited insight in that context. Cherry (2007, 2009) studied electric two-wheelers in China and noted that they do have significant environmental impacts because of the localised pollution associated with the production and disposal of their SLA batteries.

Many countries rely on coal fired power stations and so the environmental impacts associated with E-bike use need to be assessed carefully. Consideration also needs to be given to what would have been the alternative transport mode. If, for example, the E-bike replaces walking or conventional bicycle trips then the environmental case is weakened considerably.

One of the advantages of light electric vehicles like E-bikes is that their more modest power requirements makes feasible recharging away from the main electricity grid. Parker (2003) proposed that the New Zealand Energy Efficiency and Conservation Authority should create incentives for the purchase of E-bikes as part of a package that included a recharging system based on solar panels. Japan was an early experimenter with the use of solar panels to recharge E-bikes (Parker 2003). Sanyo recently completed installation of two ‘Solar Parking Lots’ for E-Bikes in Tokyo with the rooftop solar panels used to recharge the E-bike batteries and illuminate the parking lots.

It is clear from this brief review that existing information about environmental impacts associated with E-bikes is limited and patchy. There is clearly scope for future research to provide more comprehensive insight in this area.

Health and safety impacts

Growing concern over rates of obesity in many countries is stimulating interest in embedding physical activity in daily behaviour, particularly through promotion of active transport. In that context, there has been very little research conducted to explore the health implications of E-bike use and none which distinguishes those health impacts for E-PBs versus E-PABs. It is possible that these vehicles could improve activity levels for some elderly individuals who have medical conditions which make it difficult or uncomfortable to ride a conventional bike. Likewise if the E-bike user would have walked or ridden a conventional bicycle then physical activity levels would be reduced.

No detailed scientific research has identified the comparative health impacts associated with E-bikes. Rose and Cock (2003) report results from a very preliminary study which monitored the heart rate of a 22 year old person completing a 5 km on-road circuit riding a conventional bike and a 250 W E-PAB. The E-PAB maintained the rider’s heart rate intensity predominantly in the target range where cardiovascular benefit was gained and fats are used in producing energy but no lactic acid build up occurred. The absence of lactic acid avoids fatigue and muscle pain. In contrast, the conventional bicycle provided the strongest cardiovascular and fitness workout, however the intensity was often so high that carbohydrates are used for energy and a significant lactic acid build up occurred. While the results from this test cannot not be generalized, they do highlight the prospects for research of this nature to provide valuable insight. Expanding a study of this type to include a larger sample size could enhance understanding of the relative health benefits offered by both conventional bicycles and E-bikes.

Apart from the need to consider health implications for the individual users, it is also important to consider the road safety impacts from the perspective of the users and non-users of E-bikes. In that context, the Electric Bike 2000 project in Canada examined a range of safety perceptions with participants. Nearly all participants (94%) felt E-Bikes belonged on bike paths and nearly three quarters of them (70%) felt their speed on a bike path was equal or lower to that when they were riding a conventional bicycle (Lamy 2001). The study noted that 83% of respondents felt as safe on an E-Bike as on a conventional bicycle, with 95% feeling that they had complete control when the motor was running. Some respondents noted a feeling of additional safety because of the availability of increased start-up power which helped riders react more quickly and appropriately in traffic. Some respondents even went as far as to suggest an increased tendency to obey road rules (specifically relating to mandatory stops) because of the motor assistance available to help from a standing start.

A study of low speed mode safety in the USA (Rodier et al. 2003) did not distinguish any crash patterns specifically for electric bikes to distinguish them from conventional bicycles. Cherry (2007) explored the safety of E-bikes in China. Using data from two provinces he estimated fatality rates per million VKT which suggest that E-bikes had slightly higher fatality rates than conventional bicycles (0.023 fatalities per million VKT for E-bikes compared to 0.013 for conventional bicycles). However, he notes that there is lenient enforcement of vehicle standards and consequently there are a number of scooter style E-bikes that weigh over 60 kg and operate at speeds exceeding 30 km/h. While the speeds of the scooter style modes in other countries may be slower than in China, vehicles like the one shown in the bottom right of Fig. 2, at about 80 kg, are approximately four times heavier than an E-bike fitted with Li-on batteries. In a crash, the additional momentum of the heavier vehicle, particularly when traveling at speed, could have serious implications for the severity of the injuries sustained to a pedestrian or cyclist, particularly if that person was elderly.

A number of factors can contribute to reducing the risk that a crash occurs and its severity. These include:

- advances in battery technology (Ulrich 2005) which will reduce the weight of the vehicle, improving the riders ability to control the vehicle and reducing the kinetic energy to be dissipated in the event of a crash,
- enhanced infrastructure design to minimise conflict between users, and
- management of speed through measures which focus on the technology or the rider including (i) fitting control technology to E-bikes to ensure they are not capable of travelling faster than bicycles, (ii) limitations on the minimum age of riders or (iii) requirements for enhanced rider education/training.

Concerns over the maximum speed of these vehicles can arise where there is a blurring in the distinction between an E-bike and a moped or low powered motorcycle. Mopeds have a poor safety record when ridden by inexperienced, adolescent riders (Nja and Nesvag 2007).

A key issue is the extent to which E-Bikes perform differently from conventional bicycles in terms of their interaction with pedestrians and other bicyclists. As noted by Ker and Huband (2006), it is not clear in these circumstances whether the risks/hazards/conflicts are real or perceived but in either case they can influence people's behaviour. Ker and Huband (2006) outline a range of options for managing conflicts between conventional bicycles and pedestrians on shared use paths that could also have application in managing conflicts arising from E-Bike use.

One challenge to obtaining greater insight into the safety performance of E-bikes is that police crash reports, or hospital emergence department records, may not clearly distinguish bicycles from E-bikes. There is a need to ensure that safety data collection systems provide the data needed to track the performance of this mode.

Policy settings

Figure 1 highlights that there is a range of policy instruments of relevance but regulation, particularly regulations relating to vehicle standards, is by far the most common policy instrument used in relation to E-bikes. Apart from the case of China (which was discussed earlier) where ICE motor scooters were restricted because of concerns over environmental impacts, it would appear that managing either real or perceived safety impacts are a primary motivator of regulations governing these vehicles.

Historically the approach taken to regulating this category of vehicles has been one of prescriptive standards, particularly in relation to specifying a maximum power for the motor providing assistance which would allow the vehicle to still be classified as a 'bicycle'. Some jurisdictions have included a performance dimension to their standards often through either the inclusion of a maximum speed under power assistance, a requirement that power assistance be provided only when the rider is pedaling or a mandate of zero emissions from the vehicle (e.g. banning internal combustion engines as in China). It is also important to draw a distinction between:

- regulating the class of vehicle (how it relates to other classes of motorized vehicle which may require registration and insurance),
- regulating the use of the vehicle (e.g. who can ride, whether they need to be licensed and where the vehicle can be ridden), and
- enforcing the regulations.

It is not feasible, nor necessarily appropriate, here to provide a comprehensive international review of E-bike regulations or even to review differences which exist between jurisdictions within the USA or Europe. However, Table 1 summarises the important features of the regulations for E-bikes across a range of countries that span from the most liberal to the most restrictive regulations. This table highlights the diversity of the power and speed limits placed on these vehicles and also the extent to which there is an explicit link to a human powered vehicle which provides the regulatory benchmark. While the regulations refer to bicycles (implying two wheels) they commonly define the relevant vehicles as having either two or three wheels thus allowing trikes to be classified as bicycles under the regulations.

The US has the most liberal regulations in the world (in terms of the maximum power of the motor) while Australia has perhaps the most restrictive regulations (in terms of a low maximum power output). Some regulations focus on the maximum speed under power assistance, others on the need for operational pedals. Within some of the countries listed in Table 1 there are also differences in the regulations across state or provincial boundaries. Some jurisdictions specify a minimum rider age, others that the rider must either hold, or be eligible for, a car drivers licence. A lack of enforcement in China means that many

Table 1 Comparison of selected E-bike regulations

Country	Power limit	E-PB allowed?	E-PAB allowed?	Max. speed under power assistance	Other conditions and comments
USA	750 W	Yes	Yes	32 kph	Operable pedals required
Canada	500 W	Yes	Yes	32 kph	Power assistance only above 3 kph
EU	250 W	No	Yes	25 kph	Power assistance only when pedaling
Japan	250 W	No	Yes	24 kph	Max assistance at 15 kph declining to zero above 24 kph
China	–	Yes	Yes	20 kph	Little evidence of enforcement
Australia	200 W	Yes	Yes	Not specified	Operable pedals required. Power (electric or IC) must be auxiliary, not the main source of power

vehicles which are in regular use there are capable of much higher speeds than specified in the regulations (Weinert et al. 2008).

The requirements for operable pedals along with power limits on what defines a bicycle, rules out the inclusion of vehicles such as the Segway, Bik.e and Yike to this category. Many States in the US have created a special category of vehicle, termed a ‘Personal Mobility Device’, to accommodate the Segway. Without a separate classification these vehicles would presumably have to be assessed under a moped category with possible implications for driver licensing as well as the need to register and insure the vehicle.

It is appropriate to place the power limits shown in Table 1 into perspective. To propel a vehicle at constant speed, power is required to overcome rolling resistance, gravity (in the context of ascending or descending grades) and wind resistance. While the first two are proportional to only the mass (of the bicycle and rider) and velocity, the wind resistance is proportional to the cube of the velocity. Minimising the weight of the bicycle and adopting a riding position to improve aerodynamics will lower the power required to achieve a desired speed in particular circumstances. About 220 W is required to propel a bicycle carrying an average weight rider on level ground at 32 kph. Over a 1 h period an untrained cyclist might be able to deliver 80–100 W. Elite athletes may be able to produce upwards of 1,000 W in short bursts while to be internationally competitive in 1 h cycling events requires average output of around 300 W. On that basis, an additional 200–750 W would be of considerable assistance to any rider.

Since the provision of power assistance can be used to achieve a higher speed it is perhaps not surprising that many regulations address the maximum speed under power assistance. Japan’s regulations stipulate an upper limit on the speed at which power assistance can be obtained (24 kph) while in Europe the power assistance cuts off above 25 kph. The US regulations, which are structured differently, only require that the vehicle cannot be propelled by the motor at more than 32 kph. If the vehicle is designed so that a rider can combine their own power with that of the motor, a much higher speed can potentially be achieved. One model for sale in the USA is able to provide up to 750 W of assistance in addition to the power delivered by the rider and since the power assistance is only provided when the rider is pedaling, that power assistance is available at any speed.

As noted in Table 1, some regulations require the vehicle to have operational pedals or for the power assistance to only be provided when the pedals are in operation. If that is seen as an important philosophical issue, then on that basis alone, the Segway, Bik.e and the Yike, would not be classified as bicycles. An unresolved issue is whether vehicles with performance envelopes like those are most appropriately operated on bicycle facilities or in the road space devoted to conventional motor vehicles.

Even the requirement of operational pedals does not mean that the creativity of manufacturers is always aligned with the sprit of the law. As highlighted in the lower panels of Fig. 2, some existing E-bikes have the appearance of motor scooters. The model shown in bottom right panel of Fig. 2 is legal in the USA, because it has operational pedals and the manufacturer states it is limited to 20 mph under motor drive. Fig. 6 shows close up images of the pedals on that vehicle. The pedals, which the manufacturer may well have installed solely to qualify the vehicle as a bicycle, are much wider apart than on a conventional bicycle (430 mm on that E-bike versus 150 mm approximately on a conventional bicycle). The combination of the very wide pedals, the seating position and the vehicle’s 80 kg weight (due to SLA batteries) means that only those riders with very strong legs would be capable of pedaling this vehicle in the absence of motor power. As aptly described by one store representative, ‘you would feel like a circus bear trying to pedal that E-bike’. Existing regulations make this vehicle legal in the USA but not the Bik.e or the Yike. Arguably the

Fig. 6 Pedals on street legal scooter style E-bike in the USA

scooter presents a much greater risk to cyclists and pedestrians because of its inertia and spatial footprint, but the existing regulations do not explicitly consider those dimensions.

It is clear from Table 1 that there is little international consensus on the regulation of E-bikes quite apart from differences which exist across states/provinces within some countries. The scientific basis for existing prescriptive standards which focus on motor power is unclear, as is the basis for the maximum speeds under power assistance. From a policy perspective there is a need for a sounder foundation for the regulation of vehicles in this category. There is a risk, that the opportunities which vehicles in this class potentially represent in the context of sustainable urban mobility may not be realized. The risks associated with their operation in different traffic situations, and in particular when mixed with conventional bicycles, will present operational challenges for the transportation profession and potentially for the police officers who have the task of enforcing what ever regulations are in place. Adoption of a performance based standards approach to the regulation of these vehicles could present jurisdictions with scope to adopt a common regulatory framework while tailoring the relevant performance limits to suit local conditions. A performance based standards approach has already been used successfully in reforming the regulation of heavy commercial vehicles in some jurisdictions (Bennett et al. 2003). Rose (2010) elaborates on the performance based standard approach and outlines how performance envelopes could be defined for different operating spaces (footpaths/pedestrian facilities, shared or bicycle only paths and on-road) to serve as a basis for limiting the performance of the vehicles permitted to operate in each one. Such a framework would have the flexibility to accommodate differences which already exist across jurisdictions in regards to whether bicycles are allowed to be ridden on footpaths or are restricted to the carriageway. In those cases, a performance based standard would define the limiting performance envelope for each of those spaces.

Conclusions

E-bike technology is evolving and there is evidence that an increasing range of light electric vehicles will challenge the boundaries which are used to define vehicles that are classified as ‘bicycles’. While the bulk of the existing market for these vehicles is dominated by China, there are signs of growing sales in other countries. Improving battery technology, along with innovative product design, is likely to result in a more diverse range of vehicles, with lower weight and improved performance.

As many cities develop plans to increase the role that the bicycle plays in utilitarian travel there is a need to carefully consider the opportunities, and threats, that E-bikes present in that context. There would be merit in a more transparent, scientific basis on which performance-based standards were set for these vehicles in a manner which is compatible with local conditions and priorities.

Since E-bikes are an emerging vehicle type in many countries, it is necessary for the transportation profession to develop a deeper understanding of the implications of this mode of transport. Future research could refine the conceptual model presented in this paper as well as help to quantify the various linkages identified in that model.

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References

AtoB: Electric bicycle technical guide. www.atob.org.uk/questionselectric.htm (2010). Accessed 18 May 2010

Ben-Akiva, M., Bowman, J.L., Gopinath, D.: Travel demand model system for the information era. Transportation **23**, 241–266 (1996)

Bennett, D.W., Styles, E., Wright, I.: Benefits of performance based standards for heavy vehicles. Road Transp. Res. **12**(2), 54–68 (2003)

Cherry, C.: Comparative environmental impacts of electric bikes in China. Transp. Res. D **14**(5), 281–290 (2009)

Cherry, C.: Electric two-wheelers in China: analysis of environmental, safety, and mobility impacts. PhD Dissertation, University of California, Berkeley, USA (2007)

Cherry, C., Cervero, R.: Use characteristics and mode choice behavior of electric bike users in China. Transp. Policy **14**(3), 247–257 (2007)

Edmond, C.R., Tang, W., Handy, S.L.: Explaining gender difference in bicycling behavior. In: Proceedings of the US Transportation Research Board Annual Conference, 18 p (2009)

Garrard, J.: Healthy revolutions: promotion of cycling among women. Health Promot. J. Aust. **14**(3), 213–215 (2003)

Goodman, J.D.: Despite ban, electric bikes gain favor on city streets. New York Times, 20 October 2009. http://cityroom.blogs.nytimes.com/2009/10/20/despite-ban-electric-bikes-gain-favor-on-city-streets/ (2009). Accessed 15 May 2010

Hanlon, M.: Volkswagen shows production-ready folding two wheel EV Bik.e. www.gizmag.com/volkswagen-folding-bike-concept/14949/ (2010). Accessed 3 May 2010

Innovative Mobility Research: EasyConnect project description. Innovative Mobility Research, University of California, Berkeley, USA. http://www.innovativemobility.org/easyconnect/EasyConnect.shtml (n.d.). Accessed 27 July 2008

Ker, I., Huband, A.: Getting in the way of (each other's) progress: managing pedestrian-cyclist conflict on paths. In: ARRB Conference, 22nd, Canberra, ACT, ARRB Group, Vermont South, VIC (2006)

Lamy, V.: Electric bike 2000 project, report TP 13732E. Transport Canada, Montreal, Canada (2001)

Manheim, M.L.: Fundamentals of Transportation Systems Analysis, vol. 1: Basic Concepts. MIT Press, Cambridge (1979)

Moore, G.A.: Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers. Harper, New York (2006)

Nja, O., Nesvag, S.M.: Traffic behaviour among adolescents using mopeds and light motorcycles. J. Saf. Res. **38**(4), 481–492 (2007)

Parker, A.A.: Green products to help move the world beyond oil: power assisted bicycles. In: Proceedings of Solar 99, 37th Annual Conference of the Australia and New Zealand Solar Energy Society, Deakin University, Geelong, 1–4 Dec 1999

Parker A.A.: The power assisted bicycle: a green vehicle to reduce greenhouse gas emissions and air pollution. In: 25th Australasian Transport Research Forum, Canberra, 2–4 Oct 2002

Parker, A.A.: The electric powered assisted bicycle: a clean vehicle to enhance the mobility of the able, the elderly and people with disabilities. In: New Zealand Cycling Conference, Auckland, New Zealand (2003)

Parker, A.A.: The electric power assisted bicycle: a clean vehicle to reduce oil dependence and enhance the mobility of the elderly. In: International Conference on Sustainability Engineering and Science, Auckland, New Zealand. http://web.mac.com/parker15/pubs20002004.htm (2004). Accessed 18 Aug 2008

Parker, A.A.: Electric power-assisted bicycles reduce oil dependence and enhance the mobility of the elderly. In: Australasian Transport Research Forum (ATRF), 29th, 2006, Gold Coast, Queensland, Australia. http://www.patrec.org/atrf/papers/2006/1564_Parker%20(2006).pdf (2006). Accessed 18 Aug 2008

Rodier, C., Shaheen, S.A., Chung, S.: Unsafe at any speed? What the literature says about low-speed modes. In: Transportation Research Board 84th Annual Meeting, Washington, DC (2003)

Rogers, E.M.: Diffusion of Innovations. Free Press, Glencoe (1962)

Rose, G.: Evolving E-bike technology and its implications for light electric vehicle regulation. In: Proceedings of the 25th World Electric Vehicle Symposium and Exposition, Shenzhen, China. Society of Automotive Engineers of China, 6 p (2010)

Rose, G., Cock. P.: Encouraging E-Bike use: the need for regulatory reform in Australia. In: Institute of Transport Studies Working Paper ITS-WP-03-19, Department of Civil Engineering, Monash University, 37 p (2003)

Rose, G., Marfurt, H.: Travel behaviour change impacts of a major ride to work day event. Transp. Res. A **41**, 351–364 (2007)

Sanyo: Sanyo completes installation of “solar parking lots” in Setagaya, Tokyo. http://sanyo.com/news/2010/03/16-1.html (2010). Accessed 30 May 2010

Shaheen, S.A., Guzman, T., Zhang, H.: Bikesharing in Europe, the Americas and Asia: past, present and future. In: Proceedings of the US Transportation Research Board Annual Conference, 18 p (2010)

Ulrich, K.T.: Estimating the technology frontier for personal electric vehicles. Transp. Res. C Emerg. Technol. **13C**(5/6), 448–462 (2005)

Vandore, E.: Europe’s latest craze: electric bikes. Associated Press, USA Today, 15 August 2008. http://www.usatoday.com/money/autos/environment/2008-08-15-europe-electric-bikes_N.htm (2008). Accessed 19 Aug 2008

Volschenk, C.: World wide market for electric bikes. http://www.extraenergy.org/main.php?language=en&category=&subcateg=&id=3788 (2010). Accessed 4 May 2010

Weinert, J., Ma, C., Cherry, C.: The future of electric two-wheelers and electric vehicles in China. Energy Policy **36**(7), 2544–2555 (2008)

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