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RESEARCH ARTICLE

Distance, Time, Speed & Energy: A Socio-Political Analysis of Technologies of Longer Distance Cycling

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The basic laws of motion governing cycling are well understood. Consideration of the variables of energy use in cycle travel is less frequent. The potentials of both aerodynamically efficient cycle design and the augmentation of human power with e-motors dramatically reconfigure what we understand as a cycle and as cycling.

The prospect of increasing travel distance in regular journeying, coupled with the logical application of augmentation (aerodynamic and/or power), suggest a need to re-evaluate some of the ground expectations applied in design and planning for cycle travel if the cycles for which infrastructure is designed no longer conform to existing expectations of what a cycle is and how it performs.

Current e-bike performance is principally limited by normative legislative intervention, not by the intrinsic potential of the technologies. Existing decisions as to what an e-bike can (and should) be are shaped by the performance expectations of late 19th- and early 20th-century bicycle designs. Shaping modal shift for longer trips returns us to thinking about the place of cycling travel time as a function of the relationship between distance and speed. Increased speed allows for greater distance without time penalty. However, speed is itself governed by available energy, coupled with the efficiency of use of that energy. Without entirely substituting human power, e-motors allow us to augment the human power available in different ways. Changes in cycle design (velomobiles, for example) allow us to increase the efficiency of use of available power in overcoming resistance to movement.

Identifying the assemblage of cycle/cyclist as a variable, rather than a determinate object to be accommodated, raises difficult questions for cycling provision, especially in relation to longer distance travel. Drawing on the capacities of already existing technologies of cycling and e-cycling, the paper focuses on the social implications of potentially problematic interactions. It argues that new decisions will need to be made in regard to speed and distance in cycle travel and that the forging of regulations consequent on those fundamentals will substantially shape the potentials and possibilities of modal shift for longer distance cycle travel. What emerges is a politics of longer distance cycle, not simply a set of technical barriers and problems.

Keywords: speed; design conflict; infrastructure; long-distance cycling

Introduction: Beings in Motion

Cycles are machines that translate force into motion. Distance travelled (d) is a product of the speed of motion (velocity = v) and the time taken (t) (d = vt). Cycling longer distances therefore requires either more time or more speed. All motion can be expressed as an expenditure of energy (the kinetic energy of an object in motion is half of the mass (m) times the square of the speed ($0.5\ mv^2$)). A journey requires more energy as time and/or speed are increased. Rate and frequency of acceleration are particularly important in calculating energy required (the kinetic energy of an object in motion has to be imparted to that object by the force of propulsion, overcoming the various forces that retard motion). Expressed in these terms, the mechanics and energy requirements of cycle movement are well understood and subject to straightforward (if complex) calculation (Whitt and Wilson, 1982).

The focus of this article, however, is to disturb this calculation by considering how numerous other elements infringe upon a purely mechanical and technical assessment of longer-distance cycling. For example, time availability for travel is shaped by forces of gender and class (Wajcman, 2015). Social duties and familial responsibilities, together with earning capacities and social hierarchies, create pressures on the time available. Therefore, the greater the limitations placed on time for longer distances cycled, the more crucial speed becomes.

Speed in cycle travel is a product of energy input and the efficiency of use of that energy. It is therefore tied into the technologies of cycling (efficient use) and the capacities of bodies (power output). Gains in the speed of cycle travel increase the distances possible in a given time, but they also shape the dynamics of interaction between travellers moving at different velocities or with those not moving at all. Both time and speed have political and social dimensions inasmuch as they are expressions of power, both physical and symbolic. The power of a moving cyclist should not only be understood in terms of mechanics but also as a function of the relationship between the rider/cycle combination and other persons (cyclists, motorists, pedestrians) with whom they interact.

Technologies of cycling, with their varying efficiencies, translate force into motion with differing outcomes. Design variations can permit greater load carrying, more efficient translation of energy into motion (thus higher speed for the same energy input), greater rider comfort or accessibility for a broader range of bodies and bodily capacities (Cox, 2015). Technologies have politics.

The human body itself can be augmented as a power source for travel by adding motors (electric or combustion) to assist propulsion. Ultimately, of course, human input into vehicle movement can be entirely replaced by motorisation. Cycle designs exist on a continuum of possibility, not as discrete and separate entities fitted into pure categories (e.g., bicycle – pedelec – e-scooter) (Cox and Van De Walle, 2007). Legal and regulatory requirements may distinguish between vehicle categories, but these distinctions do not reflect technical considerations. Rather, they are political decisions (e.g., the EU regulation that an e-bike has a maximum assist capacity limited to 24 km/h).

It is also important to note straightaway that distance is a consumption of space by the travelling body. The quality and forms of spaces of travel create interactions between travellers: interactions are affected by differences of persons and their relative speeds of travel, and these, in turn, reflect expressions of physical power, reflected and translated into symbolic power. The spaces of travel are themselves technologies that afford different possibilities of action (Cox, 2019). Further, any discussion of power in the physical and mechanical sense also operates in the symbolic realm of power relations. The exercise of more powerful or more efficient cycling is not limited to the self but projects into the social spaces in which it operates. Interactions of faster with slower cyclists are not just a matter of speed differentials but of power differentials, connecting with longer chains of pre-existing power linked to social identity.

Consideration of the implications of longer-distance cycling requires disentangling a complex interweaving of co-constituted technological, social and political forces. It is then possible to, first, explore the ways in which the technologies involved in cycle travel shape the travel made possible; second, the ways in which travellers are constructed by those processes and practices of travel; and third, the interactions of a multiplicity of travellers. As Willis, Paige and Ahmed (2015, p565) neatly put it, "It is therefore important to think beyond the role of physical and built-environment factors when attempting to understand or predict bicycle use".

We need to identify and separately address a series of distinct elements contributing to an analysis of longer-distance cycle travel before examining their interaction. To commence, it is helpful to use a theoretical framework to understand the longer-distance cyclist as other than an isolated, choice-making subject. The Deleuzian conceptual framework of assemblages allows us to reconsider longer-distance cycling as itself an assemblage comprising rider, machine and journey space, each co-constituted and given meaning by the other and all in interaction with other journey makers (Bonham and Johnson, 2015, Cox, 2019).

We can commence our thinking about longer-distance cycle travel by analysing in turn the machinery of longer-distance cycling, the longer-distance cycling body and the longer-distance route while recognising their mutual interdependencies. For ease of analysis, we can consider each element separately before examining their entanglement, with the proviso that the possibilities of action and experience offered by the assemblage as a whole cannot be reduced to the interactions of isolated elements (Dant, 2004). The three elements (machinery, body, route) comprise the basic triptych of the cycle traveller, but they are, in turn, woven into a much broader set of social and political connections, which is the aim of the discussion to expose. As Edensor (2011) notes, commuting itself is an already privileged form of mobility dependent on a whole network of obligations and support structures. Once we have laid out salient dimensions of bodies, machineries and spaces, we can then examine the contradictions and potential conflicts exposed by a clearer understanding of the elements and their interactions for the individual journey when placed in the contexts of social spaces of other travellers. A sociotechnical analysis of the longer cycling journey can then be developed into a socio-political analysis of its practical implications.

Understanding the Cycle Traveller

In thinking about the physical and mechanical realities involved in the practical dimensions of long-distance cycling, it is easy and tempting to slip into a purely realist mode of discussion in which objective knowledge of a situation is bounded by its material realities. However, the discussion here maintains a position that not only stresses the material and symbolic qualities of interaction but also argues that practices of longer-distance cycling are not just the products of cyclists who travel longer distances but that such practices produce new realities and perspectives among those who undertake them (Watson, 2012). Consequently, longer-distance cycling is more than the product of greater speeds and/or longer time spent travelling; regularly undertaking these trips creates a different type of cyclist.

Noticeable bodily changes will accompany longer times spent or higher intensities of active travel. Higher cardiovascular fitness levels and muscular development resulting from regular repetition make longer, faster riding easier. A half-hour or more cycle journey twice a day may result in 5,000 pedal strokes per day; of course, this is true for most regular cycling journeys:

creating a habitual practice increases the likelihood of maintaining it (Heinen, Maat and van Wee, 2011). While top-end power may decrease with age, endurance is markedly less affected. Competencies and skills grow by repetition. Spending more time cycling, or achieving higher speeds, becomes easier with conditioning, enabling cycle travel to appear less onerous. Less emotional energy spent considering the physical effort involved allows more opportunity for the perception of the world around the cyclist and time for reflection.

The known health benefits of regular exercise are obvious, but we should not limit our valuation of body work to the production of physically and physiologically better-conditioned workers for the reproduction and accumulation of capital. There are other dimensions involved. More extended periods of exposure to the elemental conditions in which cycling takes place usually result in higher (even if not conscious) sensitivity to travel environments and changes in those environments (Denora, 2014). As Schwanen, Banister and Anable (2012, p522) argue, habit has "a generative and propulsive capacity brought about through repetition and belonging to body–mind–world assemblages that exceed the human individual as conventionally understood". Using Hartmut Rosa's framework of resonance, we can suggest that while repetitive cycling behaviour is not controllably predictive of a particular appreciation of the world, it does create opportunity of resonance: "a relationship to the world formed through affect and emotion, intrinsic interest and perceived self-efficacy, in which subject and word are mutually affected and transformed" (Rosa, 2019, p174). Longer-distance cycling does not create a better person, but it does increase the likelihood of changing one's relationship with the world. Nikolaeva et al. (2021) note the sense of loss incurred, particularly among those who cycle and walk to work, by respondents to their survey on the immobilities brought about by COVID-19 lockdowns.

The traveller is not a unique and isolated subject. Travel, for whatever purpose, is only one element of daily behaviour. Increased time consumption in transit means fewer available minutes for the re/production of social life (Biesecker and Hofmeister, 2010). Thus, longer-distance journeys depend upon the shapes and forms of other social, familial relationships and the labours of others. Reciprocal exchange of time taken for travel is woven into this net of obligations. The travelling subject is neither defined by their travel nor can their travel be separated from their broader network of social relations.

It is erroneous, therefore, to reduce the longer-distance cyclist to an engine for a travelling machine. The rider remains a person, woven into social obligations and constructed by shifting positions of identity within categories of class, gender, age and ability. Personhood implies relationality and social functioning, perceiving and interacting with the world around us (see Vannini, Waskul and Gottschalk, 2012). These perspectives have profound effects concerning research in cycle mobility (Spinney and Jungnickel, 2019). As found in other areas of mobilities research, novel methods and approaches have been required to engage more fully with the affective dimensions of travel (Büscher et al., 2020). Researching the travelling subject requires paying attention to their personhood and entanglements in the webs of obligation and expectation, alongside the affective dimensions of their journeying. These dimensions are problematically irreducible to simple quantification.

A second specific entanglement of the rider is that with the machine. Exploring driving rather than cycling, Dant (2004) argues that the driver-car assemblage is an inseparable combination that should be analysed in its entanglement rather than as separate elements. This insistence on the rider-cycle combination as a single entity is invaluable in thinking about longer-distance cycling. However, to analyse practices and possibilities of the combination, it is necessary to acknowledge and explore the diversities of both riders and of cycles to better understand how combinations may combine.

Machineries of Longer Distance Cycling: The Cycle

In one sense, both cycles and the spaces in which they are used are co-constituted technologies of travel, in ways that will become apparent. However, it is useful to separate them out as distinct elements to continue to identify the multiple elements interacting in longer-distance cycling. First, we consider cycles as machines.

The standard texts for analysis of the mechanics of cycling are the four editions (to date) of *Bicycling Science* (Whitt and Wilson, 1974; Whitt and Wilson, 1982; Wilson and Papadopolous, 2004; Wilson and Schmidt, 2020). Notably, the re-writing of each edition has reflected new developments in cycle design, developments in the analysis of cycling dynamics and the relative importance of particular elements of cycle design. While they focus on cycles as technological objects, the authors have continuously recognised the entanglement of technological developments with wider social factors, noting events that have changed people's attitudes to cycles and cycling, and events that have prompted commercial cycle technology innovations. The most recent fourth edition has expanded its horizons beyond the analysis of human physiology and the mechanics of cycles, with at least a recognition of the importance of space and infrastructure for cycling as transport (chapter 11).

Analysis of cycling infrastructure is usually confined to separate literatures in design and engineering, especially those intended for policy makers and deliverers (e.g., CROW, 2016; Parkin, 2018; Hessisches Ministerium, 2019; DfT, 2020). The politics of cycling infrastructure is a more recent recognition in the literature (Cox and Koglin, 2020), and it is on a synthesis of these cross-disciplinary sources that this examination rests. Particular design factors and requirements for longer-distance journeys need separate study; here it is simply the basic principles as they connect to and affect the rider-cycle assemblage and the possibilities of particular technologies. First, therefore, we need to consider the machinery of cycling.

At the outset of this discussion, it is worth highlighting that the most efficient design of a cycle (in terms of translating human power into forward motion) is *not* epitomised by the classic road racing bicycle as used in cycle sport. While it might be assumed that the bicycle design for competitions based on speed should utilise the designs capable of the highest speed per unit input of energy, this is not the case. The design of cycles for sport is regulated and constrained by the sport governing body, the Union Cycliste Internationale (UCI), and is based on historic precedent. Regulations govern everything from layout and dimensions of the frame (which must follow a basic diamond layout) to the relation of pedals to the saddle and from wheel size (and that wheels must be the same size) to the outlawing of "any device, added or blended into the structure, that is destined to decrease, or which has the effect of decreasing, resistance to air penetration" (UCI, 2021, p69). These regulations are intended to prioritise athletic capability over design innovation (Kyle, 2001). Higher efficiencies of energy use for the non-competitive cyclist *can* be produced, both by varying the design from the classic large-wheeled, diamond-framed machine demanded by the rules and by the addition of fairings and other devices to decrease resistance to air penetration.

Thus, when considering the physics of travel, we should not treat the (bi)cycle as a fixed object with a predetermined set of performance parameters. Rather, we should consider how design variations on the classic upright bicycle can make more use of the bodily energy available and how such designs have been driven by the search for better performances (and comfort) over longer distances. We can then turn to the effects of power augmentation on the cycle, including not only performance constrained within current legislative frames but also how different types of augmentation might be tailored for different types of travel. To start, we need to clarify the relation of cycle speeds and distances travelled to the energy available, remembering that the longer the distance and/or the higher the speed, the greater the overall energy required.

$$W = \frac{C_v}{\eta_{mech}} \left\{ \sum mg \left[C_r + \frac{s}{100} + \frac{a}{g} \left(1 + \frac{m_w}{\sum m} \right) \right] + 0.5 C_D A \rho C_v + C_w^2 \right\}$$

Where:
W = power (w); C_v = speed of the bicycle (m/s); η_{mech} = mechanical efficiency of the bicycle; Σm = mass of rider and machine (kg); g = acceleration due to gravity (m/s2); Cr = coefficient of rolling resistance; s = gradient (%); a = acceleration of the bicycle (m/s2); m_w = effective rotational mass of the wheels and the tyres (kg); C_D = aerodynamic drag coefficient; A = frontal area of rider and machine (m2); ρ = density of air (kg/m3); C_w = headwind (m/s) (Whitt and Wilson, 1982)

Work must be done (energy expended) to accelerate and to maintain speed. Translating the above equation into prose, three principle factors can be identified as major influences that work to prevent or retard motion. These are resistance caused by forward movement through the air (aerodynamic drag), resistance offered by upward inclines (overcoming gravity) and resistances caused by the interaction of the bicycle and the surfaces on which movement is taking place (rolling resistance). The energy required for propulsion relates directly to the sum of the forces acting to resist it. Supplying more energy than the resisting forces provides acceleration. Mechanical inefficiencies may also cause energy losses, but these can be reduced to a relatively fixed minimum for most cycles through adequate maintenance. However, this is another factor that takes time and skills. We can measure the relative efficiencies of different kinds of drive chains and the machinery which translates human muscle power (usually of legs) into the rotary motion of a wheels, but unless the retarding forces are high because of curable deficiencies (usually lubrication of moving parts!), there are few gains to be made.

Acceleration is the most energy-intensive part of movement. The more rapid the acceleration and the greater the mass to be moved, the higher the energy requirements. For the longer-distance cycling journey, where there is no augmentation of the human body's available energy resources, acceleration periods should be minimised in frequency to conserve energy. Motor vehicle drivers will be familiar with the need to press the accelerator to provide more power to speed up and to ease back when the desired speed is reached. A glance at fuel economy ratings indicates the difference between fuel consumption at a consistent cruising speed and stop-start driving. The more frequent the occurrence of stop-start situations and the higher the rate of acceleration, the greater the fuel (energy) consumption.

The same of course is true for the human body. Hence, one of the really important design features of the Dutch snelfietsroutes (literally, fast cycle route) designed for inter-urban travel is the prioritisation at crossings so that stopping and starting is minimised. Avoiding these stop-start conditions and frequent changes of velocity is not just a matter of convenience; it is a crucial dimension of the energy use element. In the design guidance for fast (Radschnellverbindungen) and direct (Raddirektverbindungen) cycle routes in Hesse, Germany (Hessisches Ministerium, 2019), specific calculation is made of the impact of time lost to stopping, waiting and accelerating in the calculation of overall travel speed on such routes.[1] Tabulations of the different likely impacts of particular junction types supply guidance to show how these losses might be minimised using accompanying layout diagrams.

Slopes due to changes in topography cannot always be avoided, but careful choices and management can minimise level changes and keep slopes to reasonable levels. Underpasses allow conservation of momentum from the initial decline and thus consume less energy than bridges: gains in momentum can be carried through to assist the climb out, whereas with a bridge, extra energy must be found to initiate a climb from normal forward motion. The work done to climb is calculated as the work needed to raise the mass of the vehicle against gravity (the vertical force component), and thus light weight becomes important in hillier areas. Similarly, mass is important in the calculation of the energy requirements needed to accelerate on level ground.

Rolling resistance depends on the relationship between the tyres of the machine and the texture of the surfaces ridden on. For this reason, this element cannot be examined outside of its entanglement with considerations of physical spaces of cycling. Steel wheels on smooth rails provide minimum friction while rolling, which is why they are used on railways. To minimise the energy wastage, the relationship between surface and wheel needs to come as close as possible to that. But a bicycle tyre also fulfils a secondary function as a form of annular suspension that allows for maximum efficiency and a modicum of comfort for the rider (Burrows, 2004). High-pressure tyres roll easily as long as the surface is relatively smooth. Roughen the riding surface (e.g., with chipseal surfaces) and much more energy is required than with a smooth asphalt surface. The compromise of pneumatic tyres is that they allow deformation to cope with the irregularity of a surface while maintaining contact.

Like transmissions, tyre pressures require user maintenance and can be altered by the rider to suit the terrain conditions. Different tyre carcass designs offer compromises between rolling resistance and resilience (resistance to puncture or other damage), longevity and traction, and most tyres have an optimal inflation pressure for the most efficient energy use (though this may alter for extreme surface conditions). Increases in rolling resistance resulting from road surface types are out of rider control. In extreme cases of bad road surfaces, the extra energy costs imposed may even justify a detour over a longer travel distance to minimise overall energy consumption.

Rolling resistance is always a compromise, and non-optimally inflated tyres are a drag, literally. But overall, few major gains in efficiency can be made other than proper tyre choice and use. Changes in rolling resistance (increases in energy requirement per metre moved) are primarily in the form of losses because of under-inflation or energy-sapping surfaces. Here, then, we arrive at a first constant requirement for longer-distance cycling routes—good, low-friction surfaces on which to ride.

In these basic mechanical considerations of cycle travel, only the mass of the machine is taken into account as a variable. However, one of the most significant factors retarding forward movement in cycling, and the dimension governing energy demand that offers most scope for alteration, is the work needed to be done to overcome air resistance. The speed attained by a bicycle for any given power output is primarily dictated by the resistance of the air, and air resistance increases as a square of the speed (see the power requirement equation above). Following this calculation, Wilson and Schmidt (2020, p229) point to the significance of reducing the frontal area and incorporating forms of streamlining to reduce the drag coefficient—precisely those possibilities for design outlawed by racing regulations. The importance of frontal area and turbulence can be easily illustrated with reference to the tuck positions adopted by racing cyclists in search of maximum speeds downhill or to the extreme flattened positions developed within the regulations for time trialling. For the ordinary cyclist, however, such extremes positions are rarely viable (comfortable or sensible). However, cycle design can be modified to minimise the frontal area.

Traditional cycles descended from the running machine of Karl von Drais in 1817 replicate an upright bipedal stance. Adopting crank drives, both direct (high bicycle) and indirect through a chain drive (safety bicycle), simply adapted this position to place the rider over the cranks. Crouching and tuck positions allow a reduction in the frontal area, but the basic relationship remains unaltered.

Seated (or recumbent) riding positions offer an alternative by placing the cranks in front of the rider, instantly reducing the overall frontal area of the rider-vehicle combination by as much as two-thirds (See **Figure 1**).

Figure 1: Typical recumbent for everyday use.
Source: Author's collection.

Figure 2: Recumbent cycle with front and rear fairings.
Source: Author's collection.

Fairings (in front of or behind the rider, or both) decrease turbulence caused by passage through the air, thus reducing aerodynamic drag. For the everyday rider, front fairings have the advantage of providing shelter from inclement weather, especially rain. Rear fairings provide space for luggage (See **Figure 2**).

The speed advantages of riding position and fairings were recognised back in the 1930s, when a new series of records were set using these technological innovations before the position was banned and regulations were put in place to define what a cycle could be for sport purposes (Schmitz, 1999; Fehlau, 2004; Cox, 2009). In contrast to the conventional cycle, upright utility or crouched racing positions, recumbent cycle designs can offer both performance and comfort advantages—the latter provided by bodyweight being supported over a larger area of the body than provided by a saddle.

Wind speed, air turbulence and the drag resulting from attempting to move through it alter close to ground level (<1 m) through complex interference effects. Informal, unpublished comparative testing (by the author, using commercially available power metering measurements) demonstrates some gains to be made by lower riding positions in blustery air.[2] However, the lower the rider position, the more difficult the balance, but this can be offset by a three-wheel layout (although this creates a 50% increase in rolling resistance and greater air drag). From these considerations emerges the contemporary velomobile: three- (sometimes four-) wheeled cycles with a full bodyshell (carrosserie) to streamline airflow, maximising these efficiency gains (see www.velomobiel.nl for examples).

Velomobiles (as illustrated in **Figure 3**) designed for everyday use (commuting human-powered vehicle (HPV)) emerge as the most efficient form of translation of human power into forward motion, as indicated in **Figures 4** & **5**. In Wilson and Schmidt's (2020) analysis, only what they describe as *Ultimate HPVs,* machines designed expressly for racing and speed record attempts, are more efficient. A properly designed bodyshell can also utilise the effects of crosswinds to provide a small amount of forward thrust by acting as a sail. The amount of extra energy harvested this way depends on the specific design of fairings and wind angles. To put the gains available in context, the amateur individual velomobilist is able to match the speed of travel of a professional cycling peloton (the massed group of riders in a road race), each of whose riders is capable of producing twice the power output per person.

Figure 4 shows the raw data for speed against power. Given that an untrained but experienced commuting rider can comfortably produce >150 W, the speed differentials provided by changes to machine design are considerable: 1 m/s equates to 3.6 km/h so that the same effort required to attain a speed of 24 km/h on a sport cycle could produce over 35 km/h in an HPV designed for commuting. It is not unreasonable to consider 24 km/h as an average (fast) cycle commuting speed; it is currently used as the cut-off point for electric assistance

Figure 3: Velomobile (commuting HPV).
Source: Author's collection.

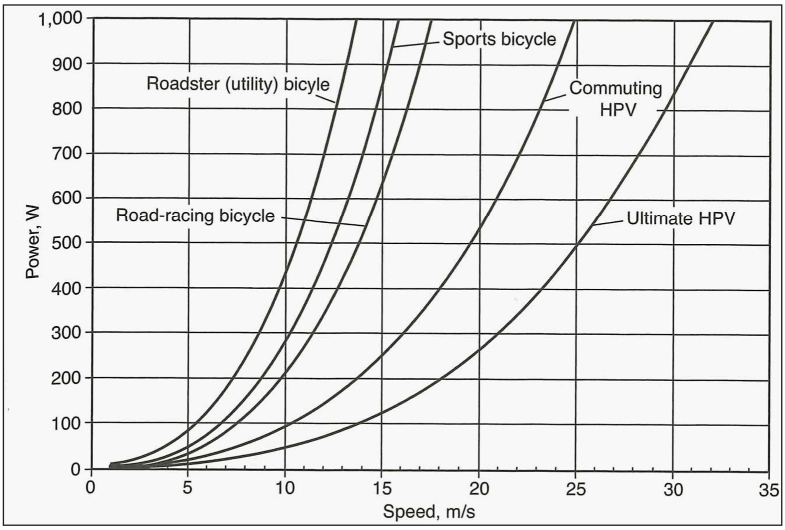

Figure 4: Speed in relation to power.
Source: Wilson and Schmidt, 2020, p189.

in EU e-bike legislation (EN 15194; see Bike Europe, 2017, for elaboration). However, average travel speed is considerably lower than cruising speed, having to take into account delays for stopping, waiting and acceleration. Design guidance for cycleway construction is also framed by an expectation of these levels of speed, so it is immediately clear that changing the design of the machine will challenge the limits of most cycle infrastructure design.

Wilson and Schmidt (2020) also illustrate this distinction in relation to the human body charting the necessary energy consumption demanded by the maintenance of given speeds while riding differing designs (**Figure 5**).

It is clear that advanced cycle designs offer significant advantages to longer-distance cycle travellers, enabling gains in speed and/or reductions in the energy requirements. Greater distances can be travelled in the same time and without increasing the energy demand on the body. That riders are diverse, body capacities differ, and the desire for exertion can differ from day to day according to weather, mood and emotion should not be forgotten. However, whatever the level of power output, **Figure 5** demonstrates the significant impacts of cycle design on the velocities attained. With the supplementation of even low-powered e-assist, these become even more marked and available to wider groups of riders.

Augmenting Body-Power: E-Cycling

To understand the potential of e-cycling, we have to similarly challenge the assumptions surrounding e-bikes as fixed and determinate objects. Any cycle can be augmented by the addition of a motor; this has been noted and acted on since the late 19th century. The focus here is on the use of exogenous power sources to augment rather than replace human energy. Current EU legislation mandates a maximum power assistance of 250 watts with a cut-out speed of 25 km/h [6.94 m/s] to remain within the limits of a fundamentally human-powered vehicle (Bike Europe, 2017). Beyond that, categories of powered cycles (speeds up to 25 km/h and power cut out at 1000 W) and speed pedelecs or mopeds (speeds up to 45 km/h and power up to 4000 W) come into play, reflecting this level of power assistance to effectively be substitution rather than augmentation. Swiss regulations allow up to 500 W assistance while still recognising the machine as a cycle, arguing that load carrying and mountainous terrain require higher peak energy use (OFROU, 2012).

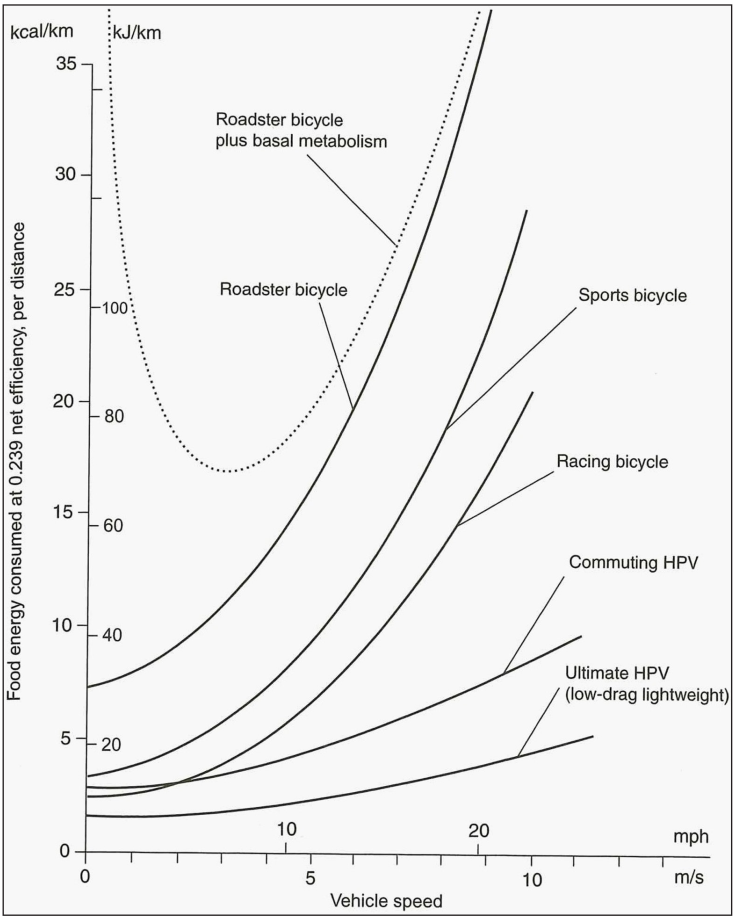

Figure 5: Speed to food energy use.
Source: Wilson and Schmidt, 2020, p201.

Returning to think about the human body, 250 W is an arbitrary figure, but it roughly reflects the bodily capacity of an experienced rider (working at effort but not peak output), with 400 W being the equivalent energy output of a trained professional. These levels of power generation can be understood as equivalent to a second person's assistance. The point of e-bikes at this level is to supplement, not to supplant, the rider's capacity. It is important for the affective dimension of cycle travel that motorisation does not entirely replace the human body's contribution to active travel.

Combining limited power e-motors with conventional cycle designs makes logical sense: riding them with even minimal input allows the maintenance of cycle mobility for a larger range of persons and for longer periods than might otherwise be sustainable. Cut-off speeds do not fix the maximum top speed of an electrically assisted cycle in, but they do ensure that above 24 km/h, the energy required for travel is entirely supplied by the human part of the combination. Thus, the expected maximum speed is still governed by the energy requirement dictated by the physics of overcoming resistance.

It is worth noting that 250 W is more power than required to maintain a speed of 24 km/h, even on a utility bicycle (see **Figure 4**). This is because maximum energy demand in cycling results from the need to accelerate (and climbing hills can be regarded as a form of acceleration in the work done to overcome the vertical force component of a slope against gravitational force). So the most valuable roles for power augmentation are in the acceleration phases and when extra power is needed to overcome gradients. For level travel, the limitations imposed on comfortable maximum speed by the aerodynamics of cycling are still dominant.

Combining power assistance with an aerodynamic cycle design (recumbent or velomobile) creates new contradictions. Because of the efficiencies, one already has a rider vehicle combination capable of travelling at 30 km/h plus for extended periods of time, using only the same bodily energy as might normally be expected. Even with a max speed cut-off, a small amount of motor augmentation (<250 W) can considerably increase the average travel speed by increasing the rates of acceleration and ensuring minimal speed decline when additional power is required to climb gradients. Through this logic, it would make sense to raise the e-bike cut-off limit to 30 km/h for aerodynamically efficient cycle designs if the basis is to allow augmentation up to the normal unassisted cruising speed. However, such a decision would run up against current limitations in infrastructure design and provision that have historically assumed a maximum 30 km/h.

The point of drawing attention to the range of innovative cycle designs and e-bike technology, and to draw attention to the potential for their combination, is to emphasise their significant potential for thinking through the possibilities of longer-distance cycling. Cycle design diversity in general allows more possibilities for more people to cycle. Some designs allow faster and more comfortable travel more easily and thus lend themselves to longer-distance journey planning (Cox, 2015). Even with assistive motor technologies, the e-cycles produced remain in the category of hybrid vehicles for active travel (Held, Schindler and Litman, 2015). Looking to the future of sustainable mobilities and significantly greater substitution of car travel, technologies that transgress the current vehicle categories (Cox and Van De Walle, 2007) are likely to be even more critical in the movement towards fusion mobilities (Neun et al., 2020).

Spaces for Cycling

Design alterations, coupled with the capacity to augment the human body power available (even when subject to cut-off maximum vehicle speeds), make the human-cycle combination a variable in the calculation of the space requirements for cycle travel. Spaces of travel then become vitally important to understand the capacities of the long-distance cycle assemblage. Historic design for cycle traffic has been premised on the limitations of the traditional upright cycle. Assumptions can safely and rightly be made as to the continued relevance of the performance envelope of this combination. E-motor augmentation and aerodynamically efficient designs both change the parameters of operation—in combination, even more so. Here we enter into the arena where physical laws and technological developments become socio-political problems.

Let us consider a free choice approach in an open marketplace for cycle technologies and without constraint on their use. Riders contemplating longer-distance travel to substitute for car journeys are increasingly likely to take advantage of technological innovations' possibilities. Commuting HPVs and e-bikes make sense. This would create growing numbers of longer-distance riders using higher-speed design cycles and those with more rapid acceleration capacities.

Successive generations of design guidance for cycle infrastructure design have been based on the assumption of cycle travel with a maximum speed of around 30 km/h; faster travel is assumed to take place on roads. This makes logical sense except for the fact that the weight and speed of motor vehicles pose an existential physical threat to those travelling under their own power. Threats arise both from the physical dangers posed by motorists and air pollution.

Cycle travel may be undertaken as an alternative to congestion, and cycling amongst motor traffic reduces the speed of travel to that of the surrounding vehicles. Even if modal shifts reduce the volume of motor traffic and tailpipe emissions are reduced by large-scale shifts to electric motoring, these problems remain fundamental in the mix of vehicles of significantly different masses.

Based on limited speeds, cycle infrastructure design is often fundamentally antagonistic towards faster cycling. Higher-speed travel makes greater demands on space. Radii for corners, braking zones and visibility are affected by the anticipated speed of travel. Existing physical infrastructures can be inaccessible or unusable to unconventional cycles. This has been highlighted in particular by the experiences of those using cycles adapted to cope with specific physical impairments, whose design cues are shared with recumbent cycles and velomobile design (Spinney, 2020).

Nevertheless, despite these not insignificant problems, these remain fundamentally technical issues that can be addressed by inclusive (and better) design. Retrofitting existing hard cycling infrastructures to make them more inclusive or capable of supporting higher-speed cycling can be intensely difficult, if not impossible. Consequently, cycling infrastructure can itself be a barrier to the encouragement of longer-distance cycling.

The assumption made above, that free choice of technologies is even possible, also needs challenging. Under current conditions, cost can be a significant deterrent to the individual purchase of innovatively designed HPVs or e-bikes. However, e-bike sales are expected to account for 50% of cycle sales in Europe by 2030 (Reid, 2020). (Notably, this is despite the lack of subsidy or promotional regimes by national governments, unlike e-motoring.) If localised infrastructural conditions are such as to make efficient use of innovative technology unfeasible, then its purchase becomes illogical. Cycle "facilities" may still include barriers, narrow 90-degree turns enclosed by walls or other impediments that make use access and use by non-standard cycle designs physically impossible, regardless of speed (see Parkin, 2018, DfT, 2020, for examples). Again, these are problems with technical solutions.

What is not amenable to technical solution are the challenges of social interaction. Rapidly travelling cycles carry high linear momentum (calculated as mass × velocity). This energy is precisely that which makes cycling with motor traffic uncomfortable, the knowledge that should a collision of any kind occur, the slower, lighter traveller will come off worst. Increased momentum, which also results from much heavier vehicles, such as laden cargo bikes, requires greater space for deceleration and for manoeuvrability, increasing its antagonism with other travellers where space is at a premium. Whilst the assumptions behind space design and allocation are of linear movements of similar velocity that require little passing space, faster cycling, whether resulting from aerodynamically efficient design or augmented power, or both, presents a threat to the slower everyday cyclist. It is only when space is not at a scarcity that significant speed differentials between users can be accommodated without intimidation. Since the focus here is on longer-distance cycling and not just existing patterns, we are looking forward to increased use and, consequently, at least potentially, competition for space if spaces remain limited.

Conclusions

The simple relationship between time, speed and distance hides a complexity of issues. If cycle speeds remain the same, the longer-distance cycling will require more time to be made available for cycle travel. Time taken in cycle commuting is commonly viewed as beneficial, as demonstrated by studies conducted during the COVID-19 lockdown, noting the sense of loss experienced by cycle commuters no longer cycling to a workplace (Nikolaeva et al., 2021). However beneficial, increased time spent in travel reduces time available in the rest of a non-expandable 24-hour day. Unless worktimes are reduced, this time is taken from that available for general social reproduction (domestic life) tasks. Gendered inequalities in the division of household responsibilities mean that increased cycle travel times may be increased intra-household inequalities. Put simply, those who cycle longer receive even greater benefits while loading more responsibility on household members whose travel time does not increase.

Encouraging longer-distance cycling whilst demanding that speeds stay around 30 km/h also denies the possibilities arising from already existing technologies of cycle travel. Technologies already exist to raise the speeds of cycle travel and thus the possibilities of longer-distance travel without the consumption of larger amounts of time. Significantly, these design innovations have stemmed from and been developed by those who seek more efficient solutions for everyday cycling rather than from the cycle industry at large (Stoffers, 2019).

Conversely, one can accept the adoption of higher-speed cycling as a solution to longer-distance cycling. Both design innovation and power augmentation, and their combination, allow for faster cycling, that is, for longer distances travelled in the same time. It is important to remind ourselves that since this paper is an exploration of longer-distance cycling, we are only considering cycling as it remains active travel. In other words, where motorisation is used as an augmentation to, not full replacement of, human power.

Faster cycle travel, however, requires a fundamental rethink of the spaces of cycling. All but a few specialised high-speed cycling routes are inadequate accommodation for higher cycling speeds. Fast cycling on low-speed infrastructure is not impossible, but it brings in a social conflict between cyclists of differing velocities and of cyclists and other users.

Existing roads, designed for the size and speed of car traffic, are, of course, eminently suited to higher-speed cycling over longer distances. However, to be made safe and enjoyable spaces for riding, the relative speed differences between cycles and motor traffic needs to be minimised. The intimidation and physical threat posed to cyclists by drivers of high-velocity, high-mass motor vehicles is a mirror of that posed by high-speed cyclists to low-speed riders and pedestrians in confined shared infrastructure. Encouraging and supporting longer-distance cycling without acknowledging these dimensions is to privilege one form of mobility over another and is unlikely to encourage more equitable social relations.

Notes

1 Calculation of travel speeds, including delay factors from Hessisches Ministerium für Wirtschaft, Energie, Verkehr und Landesentwicklung (2019) (original terminiology retained)

$$v_{Reise,j} = \frac{s_j}{\frac{s_j}{v_{frei}} + \sum_i t_{verlust,t}}$$

Where v_{reise} = effective travel speed; j = specified route section; s = route length (km); i = junction; $t_{verlust}$ = time lost from stopping, waiting and accelerating

While snelfietsroutes in the Netherlands and the various types of Radschnellwege (fast cycling routes) and radfernewege (long-distance cycle routes) in different German Länder are sometimes generically translated into English as cycle highways, their varying regulations and design specifications demand that each be treated specifically. Similar caveats apply to parallel provisions elsewhere (e.g., Denmark).

2 Comparative measurement of different machines in real-life riding locations under specific environmental conditions requires parallel, simultaneous measurement with the range of cycles to be compared, ridden at separation distances sufficient to avoid interference between vehicles. In other words, this is a nearly impossible task.

Competing Interests

The author has no competing interests to declare.

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