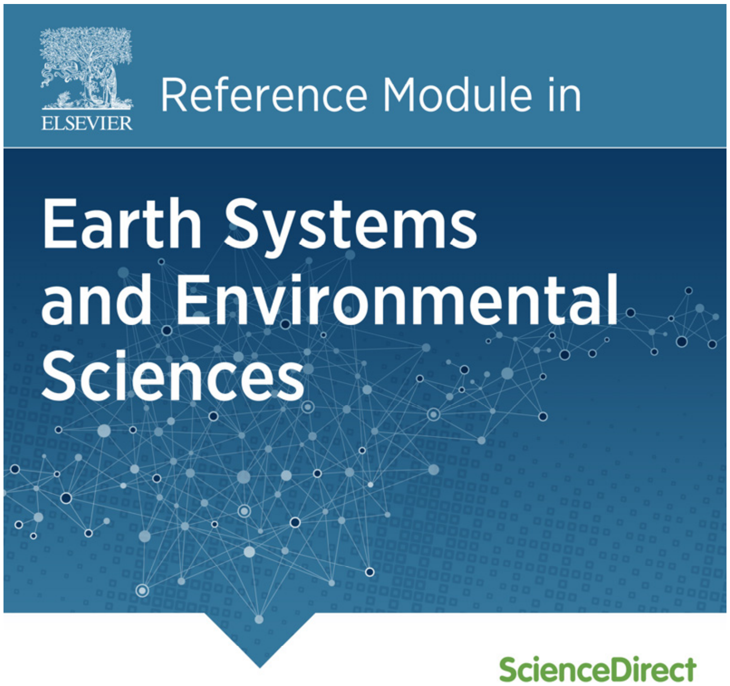

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Bicycling☆

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Glossary

Automobile Any self-guided, motorized, passenger vehicle used for land transport, usually with four wheels and an internal combustion engine.
Bicycle Any pedal-driven two-wheeled conveyance propelled by human power.
Bike lane A linear portion of a roadway demarcated for the predominant or exclusive use of bicycles.
Bike path A linear path or pathway physically separated from conventional motorized roadways for the predominant or exclusive use of bicycles.
Efficiency For transport vehicles, ratio of distance traversed to energy consumed.
Gear For bicycles, relationship between pedaling and movement, often expressed as distance traveled in one revolution of the pedals (metric gear ratio).
Sprawl Land-use patterns characterized by low population density, high automobile density, extensive road network, and little or no opportunity to travel via transit, cycling or walking.
Traffic-calming Any roadway design feature or environmental intervention intended to reduce speeds and volumes of vehicular traffic.

Definition Statement

A bicycle is any pedal-driven two-wheeled conveyance propelled by human power. Bicycles revolutionized transport in the 1800s, becoming the first mass-produced personal-transportation device, only to be pushed aside by automobiles in the twentieth century. Nevertheless, the bicycle remains the world's most numerous transport vehicle, outnumbering cars 1.5-to-1. Bicycles are still the most widely used vehicle in China and are a staple of urban transit throughout Northern Europe. They are three orders of magnitude less energy-consuming than automobiles, per distance traversed, and the most energy-efficient machine of any kind in widespread use. Moreover, bicycles conserve not just on a per-trip basis but at the social level, by encouraging proximity over distance and adding to the efficiency advantage of dense urban settlements over sprawling, suburbanized land-use patterns. In addition, cycling provides the opportunity to obtain healthful physical activity in the course of daily life, while enhancing personal autonomy vital to mental health. Accordingly, expanding the bicycle's role in urban transport is increasingly viewed as a global priority for social cohesion, urban viability, oil conservation and preservation of the climate.

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Introduction

> The most beautiful things in the world are those from which all excess weight has been eliminated.
>
> – Henry Ford, 1893

The bicycle – any pedal-driven two-wheeled conveyance propelled by human power – is the world's most numerous transport vehicle and the most energy-efficient machine in widespread use. The bicycle was also the first mass-produced personal-transportation device and created the preconditions for the development of the automobile more than a century ago. How ironic, then, that the automobile, wherever it has been widely adopted, has largely driven the bicycle from the roads, causing global petroleum usage to skyrocket, along with a multitude of other social ills.

Consider that to travel one kilometer on flat terrain, a cyclist operating a sturdy "roadster" bicycle at 10 miles per hour expends a mere 60 000 joules (14.5 kilocalories). To cover the same distance with a typical U.S. passenger car rated at 20 miles per gallon requires 115 million joules, or nearly 2000 times more energy.

To be sure, the car/bicycle energy ratio varies with the number of people carried (cars' "load factors" average more than one, but so do bicycles' in developing countries); with vehicle weight and efficiency (small cars use a third to a half less fuel than so-called light trucks, and some "hybrid" gasoline-electric vehicles use still less; and similarly for lightweight multi-gear bicycles vs. roadster bikes); and with energy losses in processing gasoline and obtaining food. Still, under most combinations of assumptions, bicycles can cover a given distance using a thousandth of the fuel of automobiles.

Moreover, as social theorist Ivan Illich observed, the distance one travels is a product of the dominant mode of transport. Bicycles go hand-in-hand with short distances and urban density, whereas cars' voracious need for space both demands and feeds suburban sprawl. In short, bicycles serve proximity while cars create distance.

Partly as a result of this vicious circle, cars have come to account for around 30% of world petroleum consumption and to produce an estimated 12% of emissions of carbon dioxide, the most prominent greenhouse gas. Expanding the role of bicycles vis-à-vis automobiles is thus an obvious prescription for a world riven by conflict over petroleum and facing social upheaval from climate change.

Over the course of the last century, cycling appeared to be losing ground, or at best running in place, in many nations' transport mixes. Today, bikes outnumber cars worldwide but are used for fewer "trips" overall and probably cover not much more than one-tenth as many person-miles as autos. Yet concerted efforts by thousands of cycle advocates in scores of countries over the past several decades are now bearing fruit, and this quintessentially human-scale and efficient machine appears poised to flourish again.

Bicycle Development

The essential elements of the bicycle are, as the name suggests, two wheels in line connected by a chain-drive mechanism, with a rider simultaneously balancing and pedaling. Some bicycle historians attribute the first sketch of such a device to Leonardo da Vinci or, as argued by author David Perry, to an assistant in Leonardo's studio. A drawing with two large, eight-spoked wheels, two pedals, chain drive, saddle supports, frame, and tiller bar appears in the *Codex Atlanticus*, a volume of Leonardo's drawings and notations dating from around 1493 and assembled in the sixteenth century. (The drawing was only discovered in 1966, during a restoration, however, leaving its authenticity open to question.)

Over the next several centuries, European inventors produced a number of self-propelled, hand- or foot-powered conveyances, all employing four wheels for stability. A practical two-wheeled device was first produced by the German Karl von Drais in 1816, and patented two years later. His 40-kg Laufmaschine ("running machine") was propelled not by mechanical drive but by pushing the feet against the ground, like a hobby horse, yet was capable of 8–9 mph speeds on dry, firm roads. Similar machines with foot-operated drive mechanisms, using treadle-cranks, appeared in Scotland in the late 1830 s. True bicycles – two-wheel vehicles with pedal-cranks located on the hub of the drive wheel – finally emerged in 1863 in France and spread quickly throughout Europe and to the United States.

Because these "pedal velocipedes" lacked gearing, each turn of the pedals advanced them only as far as the circumference of the front wheel. To achieve high speeds, designers resorted to enormous front-drive wheels, reaching diameters of 4 feet for ordinary use and up to 6 feet for racing models. Although ungainly and difficult to operate, these "high-wheelers" proliferated and led to important innovations: tangent-spoked wheels to resist torque; tubular diamond-shaped frames to absorb stress; hand-operated "spoon" brakes that slowed the wheels by pushing against them; and hubs and axles with adjustable ball bearings.

The final steps in the evolution of the modern bicycle came in the 1880 s: gearing to allow use of smaller, more manageable wheels; and chain-and-sprocket drives that transferred the drive mechanism to the rear wheel. These advances led to the so-called safety bicycle, the now-familiar modern design in which the cyclist sits upright and pedals between two same-sized wheels – the front for steering and the rear for traction.

As noted by Perry, this modern machine revolutionized cycling and is widely considered the optimum design. Innovations making bicycles safer, easier to use and more comfortable followed in quick succession – pneumatic tires, "freewheels" allowing coasting, multi-speed gearing, and lever-actuated caliper brakes operating on rims rather than tires. The safety bike transformed cycling from a sport for athletic young men to a transport vehicle for men, women and children alike. By 1893 safety bicycles had supplanted velocipedes, and by 1896 Americans owned more than four million bicycles – one per 17 inhabitants.

The bicycle boom of the late 1800s swept through the industrialized world, and bicycle manufacture became a major industry in Europe and America. One census found 1200 makers of bicycles and parts, along with 83 bicycle shops, within a 1-mile radius in lower Manhattan. The pace of invention was so frenetic that in the mid-1890 s the U.S. had two patent offices – one for bicycles and another for everything else. The lone traffic count in the U.S. to include bicycles then, taken in Minneapolis in 1906, after bicycling levels had peaked, found that bicycles accounted for more than a fifth of downtown traffic, four times as much as cars.

This "golden age of bicycling" proved short-lived. Following the classic pattern of corporate capitalism, a wave of mergers and buy-outs consolidated small shops run by enthusiasts and financed on the cheap into factories whose assembly-line efficiencies entailed high fixed costs. Overproduction followed, and then market saturation, price wars, stock manipulations and bankruptcies. Never universally popular, particularly in urban areas where swift and silent bicycles often unnerved pedestrians, the bicycle industry found its public image tarnished.

Of course, reversals of fortune were standard fare in late-nineteenth century capitalism, and many industries, particularly those employing advanced technology, bounced back. Unfortunately for the bicycle business, on the heels of the shakeout in bike manufacture came the automobile.

The Bicycle in the Auto Age

The bicycle catalyzed development of the car. Many technical advances essential to the fledgling automobile industry, from pneumatic tires and ball bearings to factory-scale production engineering and paved roads, owe their emergence to bicycles. No less importantly, the bicycle's ethos of independent, self-guided travel helped shatter the railroad-based paradigm of travel as mass transport along a fixed, linear track.

But once the car took hold, it imposed its own ideology, one antithetical to bicycles. For one thing, cars used the same roads as bicycles (the very streets that were paved as a result of bicyclists' campaigning), and through incessant noise and fumes, superior speed and sheer physical force, literally pushed bicyclists aside. What is more, as recounted by social historian Wolfgang Sachs, the engine-driven car proved a more alluring cultural commodity than the self-propelled bicycle. Though the bicycle leveraged bodily energy and broadened the individual's arena of direct activity many times over, the auto's substitution of mechanical power for muscular exertion conveyed a sense of joining the leisure class, and became equated with progress.

Thus, the bicycle's "defect of physicality," as Sachs termed it, disadvantaged it compared to the new technologies of internal combustion, electric motor drive, and flying machines. Rather than defend their right to cycle, the masses aspired to abandon it in favor of the auto. And abandon it they did, as fast as rising affluence and the advent in 1908 of the mass-produced, affordable car, Henry Ford's Model T, permitted. Although reliable data are lacking, by the end of the 1920s bicycles probably accounted for only 1 to 2 percent of U.S. urban travel, an order-of-magnitude decline in two or three decades.

A parallel devolution occurred in Europe in the long boom after the Second World War, though less steeply and with important exceptions, as we discuss below. Even now, however, around the world, bicycles outnumber cars by 1.5-to-1, primarily because of affordability. Cars cost roughly a hundred times as much to buy as a bicycle and require fuel along with maintenance, putting them out of reach of many if not most of the world's people.

The Bicycle and Human Power

According to data compiled by Vance A. Tucker of Duke University, a walking human consumes about 0.75 calorie of energy per gram of body weight for each km traveled. This is less than the rate for birds and insects and most mammals, but more than that for horses or salmon. Atop a bicycle, however, humans' energy consumption falls fivefold, to a rate of roughly 0.15 calories per gram per kilometer. As S.S. Wilson notes, "apart from increasing his unaided speed by a factor of three or four, the cyclist improves his efficiency rating to No. 1 among moving creatures and machines."

Wilson attributes the bicycle's high efficiency mainly to its economical use of human muscles. Whereas a walker expends energy raising and lowering the entire body as well as accelerating and decelerating the lower limbs, the cyclist's sitting posture relieves the leg muscles of their supporting function. Since the cyclist's feet rotate smoothly at a constant speed and the rest of the body is still, the only reciprocating parts of the cyclist's body are the knees and thighs. Even the acceleration and deceleration of the legs is optimized since one leg is raised by the downward thrust of the other. Wind resistance, the main constraint on the racing cyclist (since it varies with the square of the cyclist's velocity relative to the wind), is less significant at ordinary, utilitarian speeds (Table 1).

According to Perry, in a one-hour ride, an average person on a touring bike covering 15 km burns about 135 calories for an average power output of 50 watts; over the same hour a professional racing cyclist covers 50 km, burning 2150 calories and producing about 500 watts (0.67 horsepower).

"It is because every part of the design must be related to the human frame," says Wilson, "that the entire bicycle must always be on a human scale." He concludes, "Since the bicycle makes little demand on material or energy resources, contributes little to pollution, makes a positive contribution to health and causes little death or injury, it can be regarded as the most benevolent of machines."

Table 1 Cyclist performance factors

Factor	*Average*	*Sport*	*Pro*
Resting heart rate (breaths per minute)	70	50	30
Anaerobic threshold (breaths per minute)	160	175	185
Maximum heart rate (breaths per minute)	180	190	195
Blood volume (ml)	10	25	50
Lung capacity (l)	5	6.5	8
VO_2 Max. (O_2 uptake, ml kg^{-1}-minute)	40	60	85
Thrust (ft-lb)	15	30	55
Cadence (rpm)	70	90	100
Watts	50	200	500
Calories (kcal)	135	750	2150
Speed (kph)	15	30	50

Bicycle Variety

There is an enormous variety of bicycle types, reflecting human ingenuity, technical evolution and a broad range of design criteria including comfort, roadworthiness, speed, durability and economy. As noted by Perry, a 22-pound road bicycle contains some 1275 parts in two dozen functional systems (e.g., wheels, chains, derailleurs, cranksets). Bicycle components require a blend of lightness and durability, rigidity and flexibility to provide a variety of functions including steering, braking, balancing and climbing over diverse terrain and weather. Moreover, in much of the world, bicycles must withstand the stress of carrying several passengers or cargoes weighing several hundred kg.

Most bikes fit into one of six broad categories:

Safety bicycle – the standard design established in the late nineteenth century and still employed throughout Asia and Africa; has wide, upright handlebars, medium-width tires, heavy construction for stability and durability, and up to three internal-hub gears.

Racing or touring (*10-speed or road*) *bicycle* – the lightweight, aerodynamic design initially developed for racing in the early twentieth century and widely used today for sport; has narrow “dropped” handlebars and skinny tires, and achieves 10 or more gears through a double front chain-ring and a five-or-more-cog rear derailleur.

Mountain bike – a recent (circa 1980) design, adding light-weight racing and touring components to the classic upright-posture safety bicycle, with wide knobby tires for off-road use and a triple chain-ring for steep inclines; a “hybrid” variant with slimmer tires is popular for urban commuting in industrial countries.

Human-powered vehicles (HPV’s) are an entire class of machines combining aspects of bicycles, tricycles and even cars, developed by engineers and enthusiasts to “push the envelope” of non-motorized transportation. They include *recumbent bicycles*, in which the rider reclines against a backrest and the pedals are placed far forward. Using streamlined “fairing” to minimize wind resistance, HPV’s have achieved 60-minute speeds of 82 km hr^{-1}, vs. a maximum of 56 kph for standard racing bikes.

Utility cycles with dedicated compartments and/or trailers for carrying large and heavy loads are common in Asia and are also used in industrial nations in settings ranging from factory floors to urban food delivery.

Pedicabs conveying passengers in separate compartments are widely used in China, Bangladesh and parts of Africa, although authorities in Indonesia and elsewhere have confiscated millions in forced motorization campaigns.

Bicycles Around the World

Along with an estimated 1.2 billion bicycles, the world’s 7 billion people possess 800 million motorized passenger vehicles (cars and light-duty trucks), making for roughly one bike per 6 persons and one automobile per 9. Most of the world’s motor vehicles are in the industrial nations while a majority of bicycles are in the developing world (Table 2).

Although precise data aren’t available, it’s likely that the average car is driven around 10 000 miles a year, while the average bicycle probably logs fewer than 750 miles. Based on these rough figures, the world’s autos collectively travel nearly ten times as many miles as cars, though the two modes’ shares of *trips* are much closer.

Three countries or regions are of particular interest: China, the world’s most populous nation and still a bicycling stronghold in spite of state policies designed to replace bicycles with cars; the United States, the *ne plus ultra* of automobile usage; and northern Europe, where public policy restraining automobile use has brought forth a bicycle renaissance amidst affluence.

China

Large-scale bicycle manufacture and use became a centerpiece of Chinese industrialization and urbanization shortly after the 1949 Revolution. By the 1980s, bicycle production for domestic use and export combined had reached 40 million units a year, or more

Table 2 Bicycles and automobiles in selected countries and regions (circa 2010)

Country or Region	*Bicycles*	*Autos*	*Bicycle/Auto Ratio*	*Bicycles per 1000*	*Autos per 1000*
China	435 000 000	60 000 000	7	333	44
India	80 000 000	20 000 000	4	70	17
Japan	70 000 000	60 000 000	1.2	560	480
Germany	60 000 000	40 000 000	1.5	750	500
Netherlands	12 000 000	6 000 000	2	750	375
United States	120 000 000	200 000 000	0.6	400	670
Africa	50 000 000	25 000 000	2	50	25
World	1 200 000 000	800 000 000	1.5	170	114

than world car output at that time. Today, China's 1.3 billion people own an estimated 435 million bicycles, more than a third of the world's total, but down considerably from the peak in the mid-1990s.

At that time, bicycles were the mainstay of urban transportation throughout China – traffic controllers in the largest cities sometimes counted up to 50 000 cyclists per hour passing through busy intersections – and mass cycling was a seemingly indelible part of China's image in the world.

Cycling's status has eroded over the past two decades, perhaps irreversibly, as China has patterned urban development on the skyscrapers-cum-highway model that engulfed U.S. cities in the 1960s. Although today China manufactures an estimated two-thirds of the world's 130 million bikes produced each year, most of this is for export. China's automobile industry became the world's largest in 2008, and production is approaching 20 million units per year. Motor vehicle registrations surpassed 60 million in 2009 and are expected to reach 200 million by 2020. "Bicycle boulevards" in Beijing and other major cities have been given over to cars, and the safety and dignity enjoyed by several generations of Chinese cyclists are crumbling under the onslaught of motorization.

Yet some Chinese cities still register some of the highest cycling rates in the world, with Tianjin, Xi'an, and Shijiazhuang reportedly relying on bicycles for more than half of all trips. Nevertheless, the ongoing conversion of the world's premier bicycle nation into a car-cum-transit society is eerily reminiscent of America a century ago.

The difference is that China's population is an order of magnitude larger than that of the U.S. in 1900, making the fate of cycling in China a matter of global moment. If China were to match the U.S. per capita rate of auto use, world CO2 emissions would rise by one-sixth, a huge blow to the effort to limit greenhouse gases and stave off global climate disruption.

United States

Like no other society in history, the U.S. has been dominated spatially, economically and psychologically by automobiles. Registered autos outnumber bikes by nearly two-to-one, and five of every six travel trips by Americans are by car (with walking accounting for most of the remainder). A mere 1% of U.S. trips are by bicycle, and a majority of these are for recreational rather than "utilitarian" riding. The reasons are manifold, though each may be losing some of its grip:

Car Culture: America's cultural triumvirate of mobility, physical inactivity and speed has enshrined the car as the norm and consigned cycling to the margins. In turn, the perception of cycling as eccentric or even deviant has contributed to an unfavorable climate for cycling that has tended to be reinforcing. Of late, however, car ownership, use and allegiance by U.S. millennials is lagging that of previous under-30 generations.

Sprawling Land Use: A majority of Americans live in suburbs, where streets and roads are expressly designed only for motorized vehicles. Urban areas are more conducive to cycling, with smaller distances to cover and congestion that limits motor vehicle speeds. But cities too have been engineered around autos, and only a few have marshaled the fiscal and political resources to ensure safety, much less amenity, for cyclists. Nevertheless, urban demographics and engineering are changing. Cities are proving increasingly attractive to young people, and city planners are increasingly providing biking infrastructure to capitalize on a growing desire for active transportation and car-free lifestyles.

Subsidized Driving: Low gasoline taxes, few road tolls, and zoning codes requiring abundant free parking have been a standing invitation to make all journeys by car, even short trips that could be walked or cycled. This too is changing, facilitated by digital payment systems that let municipalities charge for car trips incrementally and intelligently.

Cycling Danger: A bike ride in the U.S. is several times more likely to result in death than a trip in a car, with 700 cyclists killed and many thousands seriously injured annually. The prospect of accident and injury is a powerful impediment to bicycling in the U.S. Moreover, cycling's actual risks are compounded by cultural attitudes that attribute cycle accidents to the supposedly intrinsic perils of cycling, unlike motorist casualties, which are rarely interpreted to mean that driving as such is dangerous.

These inhibiting factors have been mutually reinforcing. Particularly with America's pressure-group politics, the dearth of broad participation in cycling has severely limited support for policies to expand it. In turn, the lack of a robust and visible presence of cyclists on the road has exacerbated drivers' inclination to see cyclists as interlopers and treat them hostilely.

Yet the same "feedback loops" that have suppressed U.S. cycling can operate in reverse. Over the past two decades, cities as geographically, topographically, meteorlogically and culturally diverse as Portland (Oregon), San Francisco, Minneapolis and

Chicago have increased their bicycle mode share at least twofold and as much as fivefold, according to Pucher & Buehler, and New York City has registered comparable gains in just the past half-dozen years. The increases are credited to co-ordinated measures including networks of on-street bike lanes, provision of bicycle parking, integration of cycling with public transport, traffic-calming measures, official and unsanctioned large-scale cycling events, and widespread support of bicycle culture.

Northern Europe

The lone region in which bicycling has co-existed with affluence and automobiles for decades is Northern Europe. Despite high rates of car ownership, more than a half-dozen nations there boast at least 8% of urban trips by bike, surpassing the U.S. mode share by roughly an order of magnitude.

The highest bike share is in the Netherlands, with 26% of urban trips. Denmark is next with 16%, followed by Germany at 10% and Sweden, Finland and Belgium at 8-9%. (Note that the reported U.S. bicycle modal share is for all travel, a tougher standard than the urban share reported for Europe.) Also notable is women's high share of cycling trips in the Netherlands, Denmark and Germany (56%, 55%, and 49%, respectively) vs. just 24% for the United States; and seniors' high cycling rates (with people 65 and over making 23%, 15% and 9% of their urban trips by bicycle in the three European countries).

Robust bicycling levels in Northern Europe are neither automatic nor accidental, but an outcome of deliberate policies undertaken since the 1970s to reduce oil dependence and to help cities avoid the damages of pervasive automobile use. Not only are auto tolls, taxes and fees many times higher than in the U.S., but generously funded public transit systems reduce the need for cars, increasing the tendency to make short utilitarian trips by bicycle. Particularly in Germany, Denmark and the Netherlands, comprehensive cycle-route systems link traffic-calmed neighborhoods in which cycling alongside cars is safe and pleasant. According to Pucher & Buehler, these policies engendered increases in per capita cycling from the late 1970s to 2005 of 65–70% in Germany, 20–25% in Denmark and 45–50% in the Netherlands.

Indeed, the same kind of feedback loops that have held back cycling in the United States nurture it in Northern Europe. Both density and bicycling are encouraged by policies ranging from provision of transit and cycle infrastructures to "social pricing" of driving; and Northern European states refrain from subsidizing sprawl development. Not only do a majority of Europeans live in cities as a result, but population densities in urban areas are triple those in the U.S.; correspondingly, average trip distances are only half as great, a further inducement to cycle.

Bicyclist Safety and Danger

The bicycle's marvelous economy and efficiency have negative corollaries. First, unlike three- or four-wheeled conveyances, bikes are not self-balancing. Continuous motion is required to keep them upright, and they can tip and crash due to road defects, mechanical failure or operator error. Second, crash-mitigation measures such as seat belts, air bags and crumple zones that have become standard in automobiles aren't feasible for bicycles; only helmets offer a modicum of protection, and less than is commonly believed (see discussion below).

The exposed position of cyclists on the road makes them vulnerable to motor vehicles. Surpassing bicycles several-fold in velocity and at least 100-fold in mass, automobiles have a thousand times more kinetic energy to transfer to a bicycle in a collision than vice-versa. Not surprisingly, while most bicyclist injury-accidents occur in falls or other bike-only crashes, most of the *severe* injuries and fatalities result from collisions with cars. Approximately 90% of bicycle fatalities (95% for child cyclists) in the United States have motorist involvement, and the percentages elsewhere are probably as high.

Ironically, bicycles pose little danger for other road users, and far less than automobiles, whose users exact an enormous toll on themselves and each other. Worldwide, total road deaths are estimated at 1.25 million people each year, with many millions disabled. Based on "Disability-Adjusted Life Years," a statistic incorporating permanent injuries and the relative youth of victims, the World Health Organization ranked road deaths the world's ninth worst health scourge in 2004, the most recent year for which data were available.

Worldwide Differences

Bicycle safety policies differ widely around the world, as illustrated in the regions profiled above. China was too poor until recently to invest in bicycle safety measures, but it was likewise too poor for the motorized traffic that can make such measures necessary. Historically, cyclists in China and most other Asian nations could rely on sheer numbers to maintain their right-of-way. In the U.S., bicycle safety measures have focused on changing cyclist behavior, primarily increasing helmet use, especially by children, and training cyclists to emulate motor vehicle drivers through "effective cycling"™ programs. Little effort has been made to address the nature and volume of motor vehicle traffic or the behavior of drivers toward cyclists, although this too is now changing in response to the increased numbers and enhanced social status of cyclists.

In contrast, bicycle safety in Europe is promoted holistically as part of policies to encourage cycling and universal road safety. Germany and the Netherlands promote both through provision of elaborate and well-maintained cycling infrastructure, urban design oriented to cycling and walking rather than motor traffic, disincentives and restrictions on car use, and enforcement of traffic regulations that protect pedestrians and cyclists.

The European safety model is validated by low fatality rates. Despite rising cycling levels noted in Section VI, cycle fatalities fell by 65% in Denmark, 70% in the Netherlands and nearly 80% in Germany from 1970 to 2008. U.S. cycle fatalities fluctuated throughout this period, ultimately declining by only 10%. Currently, bicycle fatalities per km cycled are several times lower in the three European countries than in the U.S., and injury rates are an order of magnitude less. Perhaps most tellingly, although Germany, Denmark and the Netherlands have higher per-km fatality rates for auto users than the U.S., their overall per capita rates of road deaths are one-half to two-thirds lower, in large part because cars are used less there.

Cycle Helmets

Helmets are a polarized subject in bicycling. Many observers trace the origins of the debate to a 1989 epidemiological study in Seattle, WA associating helmet use with an 85% reduction in brain and head injury. Yet this dramatic difference in injuries between helmeted and bareheaded cyclists has not been observed in population-level research, perhaps because helmet use may be a "marker" for cycling behavior in which crashes are less severe, rather than a mitigator of injury. Even the Seattle authors later scaled back their results considerably, to a mere 10% reduction in severe injuries when body and not just head trauma is taken into account. Nevertheless, the initially reported connection between helmet use and injury reduction has sparked self-perpetuating campaigns to compel helmet use by child cyclists (later extended to skateboards, roller-skates and scooters) and to promote helmet-wearing by adult cyclists. Currently, four of Canada's 13 provinces, a sprinkling of U.S. municipalities, and the whole of Australia require children and adult cyclists alike to wear helmets.

Whether these campaigns have been useful or not is difficult to say. Child cycling fatalities decreased in the U.S. in recent decades, but largely because fewer children were cycling. Adult fatalities increased before leveling off in absolute terms, but have risen relative to overall road deaths, since crash-mitigation equipment enjoyed by motorists is not available to cyclists. Yet despite the tenuous links between helmet promotion and cycling injury prevention, the "helmet paradigm" is firmly established in U.S. policy.

In Europe, where injury prevention is subordinated to broader health promotion, and social responsibility is emphasized alongside individual accountability, helmets are considered irrelevant or even counter-productive to health. The influential British social scientist Mayer Hillman contends that cardiovascular and other physiological and psychological gains from cycling far outweigh riders' crash risks, even in unsatisfactory road environments. Hillman's paradigm of *cycle encouragement* holds that cycling is so beneficial to individuals and society that no interferences should be tolerated, including the subliminal message helmets may send about cycling dangers and cyclists' differentness from other members of society. Following Hillman's lead, public health experts Peter L. Jacobsen and Harry Rutter maintain that "the most important issue in bicycle safety is that the danger posed by motorized traffic discourages cycling" and thus robs society of cycling's health benefits as well as its wider social and environmental gains.

Safety in Numbers

Anecdotal evidence has long suggested that the per-cyclist frequency of being struck by a motor vehicle declines as the amount of cycling on a road or in a region increases. This "safety in numbers" effect is thought to occur because as cyclists grow more numerous and come to be an expected part of the road environment, motorists become more mindful of their presence and more respectful of their rights. The implication is that adding more cyclists to the road makes it less likely that any individual cyclist will be seriously injured in traffic. Conversely, removing cyclists from the traffic stream raises the risk to those who continue to cycle.

Safety-in-numbers offers a plausible explanation for the fact that per-km cycling fatality rates in Germany and the Netherlands are four times less than in the U.S. while cycling rates are at least an order of magnitude greater – though of course the causal chain works in both directions. Time-series estimates of this effect point intriguingly toward a "power law" relationship of approximately 0.6 between cyclist numbers and cyclist safety. According to this relationship, the probability that an individual cyclist will be hit by a car on a particular road declines with the 0.6 power of the number of cyclists on that road. Say the number of cyclists doubles. Then, since two raised to the 0.6 power is 1.5, each cyclist would be able to ride an additional 50% without an increasing probability of being struck. (The same phenomenon can be expressed as a one-third reduction in per-cyclist crash risk per doubling in cycling volume, since the reciprocal of 1.5 is 0.67.)

The implications for cycling are profound. Countries such as the United States that have based safety promotion on cyclist behavior modification might reconstruct safety in a social context. One consequence would be to de-emphasize helmet use in favor of facilitating broader participation in cycling and stimulating a "virtuous circle" in which more cycling begets greater safety which in turn encourages more cycling. As well, countries such as China might reconsider policies that are eroding large-scale cycling, lest safety-in-numbers in reverse lead to the kind of downward spiral that befell the U.S., in which bike-riding was limited to small numbers of enthusiasts and others with no alternative.

Bicycle Policies

Policies to support and "grow" bicycling fall into three categories: cycling infrastructure, cyclists' rights, and disincentives to driving.

Cycling infrastructure policies aim to attract cycle trips by providing "facilities" such as on-street bicycle lanes, off-street bicycle paths (e.g., "greenways") with separate right-of-way, bicycle parking, and integration with the metropolitan or regional transit system. Constructing and maintaining such facilities has proven politically popular in some U.S. localities and has absorbed most of the $5-6 billion spent on bicycle programs from 2003 through 2012.

A relatively recent infrastructure development is distributed networks of public bicycles for short-haul trips – an innovation known as bike share. A 2013 survey by Earth Policy Institute reported 500 cities in 49 countries with bike-sharing programs fielding a combined half-a-million bicycles. The typical system employs a fleet of uniform, utilitarian, adjustable-seat bikes; docking stations sprinkled around the city and especially at transit stations, commercial hubs and high-density residential areas; and smart-card technology affording quick access and return. Bike share already accounts for a third or more of bicycle travel in some cities and is becoming a path toward "normalizing" urban cycle use.

Cyclists' rights initiatives seek to improve the legal standing of cycling in order to make cycling safer and more socially validated. Exerting closer authority over driver conduct through the legal system, police enforcement and cultural shifts would, it is felt, reduce both actual and perceived threats to bicyclists and thus encourage cycling.

Disincentives to driving are policies to reduce motor traffic by making driving less attractive economically and logistically. Measures falling under the rubric of "social pricing" of automobiles include gasoline taxes, "carbon" taxes on fossil fuels, road pricing (fees on each km driven) and restructuring auto insurance and local road taxes to pay-per-use.

That these three kinds of initiatives are complementary is seen by examining Germany, Denmark and the Netherlands, which have used all three to maintain and restore bicycling since the early 1970s. No single approach is sufficient, and each supports the others by increasing opportunities and rewards for cycling and establishing a social context in which cycling is "valorized" as appropriate and praiseworthy.

Bicycle Prospects

Strong societal currents are propelling bicycling forward at the same time that powerful forces are discouraging it. Much hangs in the balance, both for billions of the Earth's peoples who may wish to master their own mobility through cycling, and for our planet's ecological and political well-being.

Each trip cycled instead of driven conserves gasoline and averts the addition of climate-altering carbon dioxide to the atmosphere. The potential effects are large, given that passenger vehicles account for almost a third of global petroleum consumption and generate one-eighth of CO2 emissions. "Green cars" are no more than a palliative; even if autos were made five times more efficient, a world where everyone drove at the U.S. per capita rate would emit more CO2 than at present.

Sustaining Earth's climate and political equilibrium thus requires robust alternatives to the American model of one car per journey. Moreover, bicycles conserve not just at the per-trip level but at system scale, by allow proximity to substitute for distance and reinforcing the efficiency advantages of dense urban settlements over sprawling, suburbanized land-use patterns. Ecological imperatives are therefore a potent reason to maintain bicycling in China and other developing countries and to foster it in automobile-dependent societies such as the United States.

Health promotion is a major rationale as well. As noted, road traffic accidents are among the world's ten leading causes of death and disability, and sedentary lifestyles are recognized as a prime contributor to the global obesity epidemic and of ill health in general. In contrast, cycling lets individuals integrate moderate but energetic physical activity into daily life – in line with recommendations of the U.S. Dept. of Health and Human Services, among other governmental agencies – while enhancing personal autonomy and aiding mental health.

Yet motorization itself is a powerful suppressant to cycling, and not just in the often-lethal competition between cars and bikes. Just as pernicious is the automobile's grip on transportation's "mindshare" – the automatic equation of mobility with motor vehicles, and motor vehicles with success – that leaves bicyclists, individually and institutionally, on the outside looking in.

Large-scale cycling is firmly ensconced in the countries of Northern Europe, which view it as integral to national objectives of reducing greenhouse gases, sustaining urban centers, and promoting health and self-guided mobility. Rejuvenating mass cycling in China and developing it in the United States would seem to require dethroning the automobile as the symbol and engine of prosperity and curbing its immense financial and political power – a tall order. Nevertheless, the advent of bike-sharing systems in both nations could pose a challenge to auto hegemony. In Hangzhou, a city of nearly 9 million people, cycling's mode share dropped from 43% in 2000 to 34% in 2007 but rebounded to 37% after bike sharing was introduced, according to Earth Policy Institute. In 2013, New York joined Boston, Washington DC and other U.S. cities as sites of large-scale bike-sharing programs.

The bicycle – a pinnacle of human efficiency and an icon of vernacular culture for over a century – will survive. Whether it will again flourish may help determine how, and if, humanity itself survives.

Further Reading

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