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Of Bicycles, Bakelites, and Bulbs
Toward a Theory of Sociotechnical Change

Wiebe E. Bijker

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I also benefited from discussions with research groups in various places. Chapter 4 was largely written during my stay as visiting professor at the Technical University in Vienna. Chapter 5 received its penultimate and most radical revision during my visit to the Technical University of Denmark. The research group "Technological Culture" in Maastricht provided an important forum for discussing drafts of chapters 4 and 5. Tannelie Blom, Ton Nijhuis, Rein de Wilde (Maastricht), Rob Hagendijk (Amsterdam), Ulrik Jörgensen (Copenhagen), and Eduardo Aibar (Barcelona) have tried to help me avoid various pitfalls in the discussions of power in these last chapters (though I probably still fell into a good number of them). Ed Constant, Tom Misa, and Paul Rosen have provided stimulating discussion at various stages of writing.

Making a book, however, is not just a matter of academic research and teaching. In the final stage, the comments of two anonymous referees were stimulating and challenging. Bernie Carlson, Larry Cohen, and Trevor Pinch succeeded in critically following and shaping the project without jeopardizing our relationship as co-editors of the Inside Technology series. Melissa Vaughn did the crucial editing and production job of turning the manuscript into a book. Such were the professional ties, many of which have turned into friendships.

But the last—and in some respects most important—part of the weave has yet to be mentioned. This book could never have been written solely within the confines of academia. Liselotte, Else, and Sanne continually reminded me of this in their need for cooking and caring, and their claims to bicycle and football, to playing piano and cello. But mainly by just being there, three daughters provide a strong, continuous demonstration that life is more, and more complex, and more interesting, than the activities in the academic compartment of society. This book is dedicated to Tonny, who complements all those mentioned above as skeptical commentator, as supportive friend, as mother of the daughters, as love.

1
Introduction

The stories we tell about technology reflect and can also affect our understanding of the place of technology in our lives and our society. Such stories harbor theories. But stories can be misleading, especially if they aim for neatness and therefore keep to the surface of events. This book will be about both stories and theory. I will start with some of the stories:

- In 1898 a female cyclist was touring the English countryside. She was dressed in knickerbockers, which seemed the most practical and comfortable clothing for a woman on a safety bicycle. After a good lap, she spotted an inn and decided to take a bit of refreshment. To her surprise, the proprietor refused to seat her in the coffee room and insisted that, if she wanted service, she would have to go into the public bar. The innkeeper's objection centered on the cyclist's clothes; evidently she did not think it proper for a woman to appear in public in anything but a long skirt. The cyclist objected, of course, and eventually brought her grievance to court, which sided with the right of the innkeeper to refuse service. This was not the end of the story, though. This lost case had an important afterlife as a symbol in the battle for women's rights. Can we say, then, that the design of this technological artifact, the safety bicycle, which allowed our cyclist to travel on her own and to choose a more comfortable form of dress, played a role in challenging traditional gender roles and building modern society?[1]
- "God said, 'Let Baekeland be,' and all was plastic." Few individual inventors have had as great an impact on society as did Leo Baekeland. This brilliant inventor created the first truly synthetic material to replace natural and seminatural materials such as ivory and Celluloid, and developed many of the applications that led society into the era of plastics. At first glance, Baekeland seems an exemplar of the American scientist-

2

King of the Road: The Social Construction of the Safety Bicycle

2.1 Introduction

Before the bicycle became "King of the Road,"[1] it was the "Prince of Parks." Aristocratic young men drove high-wheeled bicycles in Hyde Park to show off for their lady friends. The high-wheeled machine was not meant to provide ordinary road transportation, however, or to enable families to tour the countryside. These transportation and touring aims would be fulfilled by the safety bicycle—a low-wheeled vehicle with a diamond frame and a chain drive on the rear wheel—in the 1880s and 1890s. The process of emergence of this new bicycle will form the focus of this chapter.[2]

Why did the safety bicycle emerge only after the detour of the high-wheeled bicycle? A review of bicycle history shows an increase and subsequent decrease of front-wheel diameter, beginning and ending at about 22 inches, with a maximum of some 50 inches in between. The main difference between the first and last bicycles is the mechanical means of their propulsion: boots on the ground for the former versus a chain drive on the rear wheel for the latter. In retrospect, it seems that all the technical elements needed to modify the first bicycle (a "running machine") into the safety bicycle had been available since the time of Leonardo da Vinci. Why, then, did it take more than half a century for gears and a chain drive to appear on a working bicycle? What strange detour was this from the sure path of technical progress?

The high-wheeler has been described as a mechanical aberration, a freak. Its faults were its instability, the insane difficulty of getting on and off, and the fact that the large front wheel was driven and steered at the same time, which could be very tiring on the arms (Ritchie, 1975: 122). This will be the leading historical question of this chapter: How can we understand this detour as part of the construction of the safety bicycle?

The chapter has a theoretical as well as a historical goal. We will "extract" a descriptive model from the story of the bicycle, and then test this model by applying it to the other cases studies in the book.

I will start with an impressionistic sketch of early bicycle history, from the first machines up to the high-wheeled Ordinary bicycle. There follows a more detailed account of the specific groups involved in the transformation of the bicycle from high-wheeler to safety bicycle. I will then interrupt the flow to introduce the first element of the descriptive model: the idea of *relevant social groups.* A second methodological section will focus on problems involved in describing technical artifacts. The sixth section then shows how several solutions to the "problems" of the high-wheeler, especially the problem of safety, were designed in the form of alternative bicycles. This suggests the introduction of a crucial concept for our descriptive model: *interpretative flexibility.* The invention of the air tire—or rather its reinvention—is recounted in the next section. This proved to be a significant step in the formation of the safety bicycle and leads naturally to the introduction of the third and fourth elements of the descriptive model: *closure* and *stabilization.* The chapter closes by tracing in detail the stabilization process of the safety bicycle.

2.2 Prehistory of the Bicycle: From "Running Machine" to Ordinary

Leonardo da Vinci seems to have thought about the possibility of a humanly propelled vehicle that would be stable even though it had only two wheels (figure 2.1). The light-brown coloring of the drawing suggests that the machine was to be made of wood; it had wheels of equal size, a saddle supported by the rear axle, and a chain drive on the rear wheel. Da Vinci's role in this design has not been proved, although it is likely that the drawing was made in his atelier, thus suggesting his indirect involvement at least. The bicycle drawing in the *Codex Atlanticus* was found during a recent restoration. Data about da Vinci's pupil Salai, who is mentioned on the pages, suggest that the drawing was made around 1493 (Reti, 1974), at which time da Vinci was engaged in designing gears and chains, one of which looked much like that depicted in the sketch. There is no indication, however, that this vehicle was ever constructed.

The first vehicles with two wheels arranged in line were built at the end of the eighteenth century. Although there are some reports about machines of even earlier date (Minck, 1968; Daul, 1906), most accounts identify the Célerifère as the first such vehicle (figure 2.2). It had the

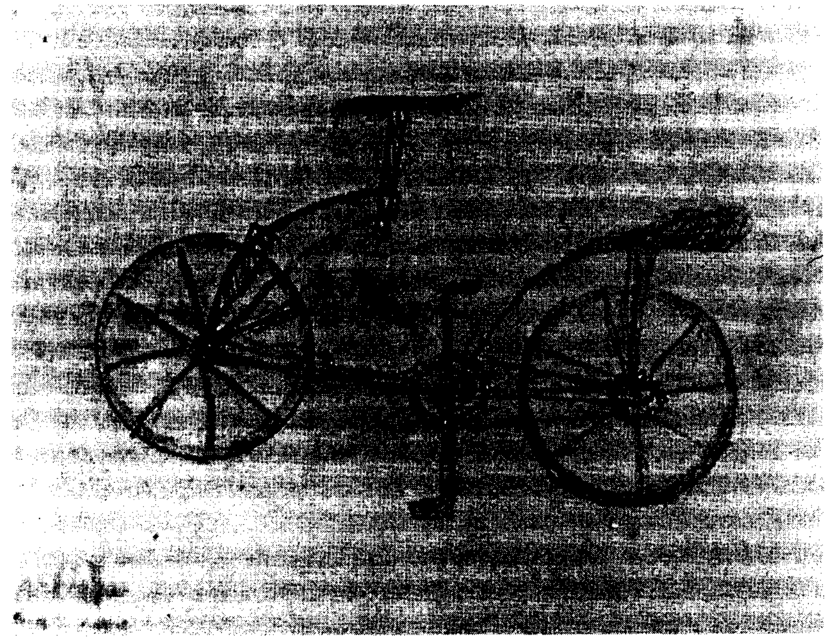

Figure 2.1
A bicycle-like machine, probably drawn by one of Leonardo da Vinci's pupils (*Codex Atlanticus*, page 133 verso; photograph courtesy the Biblioteca-Pinacoteca Ambrosiana in Milano).

form of a wooden horse with two wheels. Its maker is unknown. The Comte de Sivrac, a young man known for his eccentricities, is reported to have been seen riding it in 1791 in Parisian parks. While sitting on the "horse," he pushed the vehicle forward with his feet. Because there was no steering wheel, he had to go through a tedious procedure whenever he wanted to make a turn: stop, lift the machine, and then put it down facing the new direction. De Sivrac worked hard to earn the applause of the people walking in the Bois de Boulogne: "Il s'arrête de temps en temps, fort essouflé, fort fripé, mais toujours souriant."[3] Three years later the machine, renamed the *vélocifère*, had become a pastime for some of the more dashing young men of Paris, who showed their skills in the gardens of the Palais-Royale. Races were even held along the Champs Elysées. The initial enthusiasm faded quickly, however, after several riders strained themselves in lifting the heavy machines and others suffered rupture of the groin (Woodforde, 1970).

The turning problem was solved in 1817 by Karl Friedrich Christian Ludwig, Freiherr Drais von Sauerbronn in Mannheim. Karl von Drais,

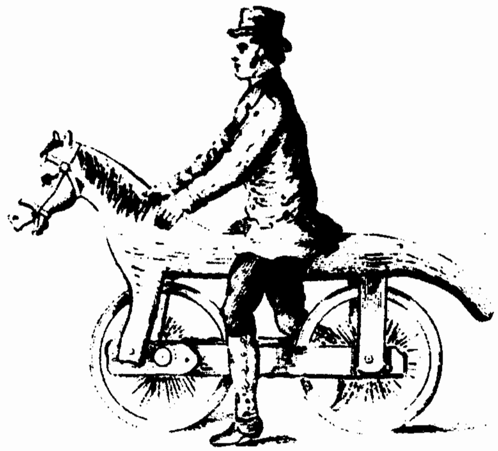

Figure 2.2
The "Célerifère" of 1791, in 1793 renamed the "vélocifère."

as he is generally known, was employed by the Baden court as master forester and chamberlain. His true calling, however, was mechanical construction. He invented several machines, such as a meat chopper, a typewriter, and a periscope, which left no deep trace in history. In 1817, however, he constructed a *Laufmaschine,* a "running machine" that consisted of a wooden frame with two wooden wheels of equal size positioned in line; the front wheel was able to turn. Between the wheels, on the frame, a cushioned saddle was mounted (figure 2.3). In front of the saddle was a cushioned bar on which the underarms could be rested. In the first version, steering was done with this bar; later Drais provided a separate steering handle in front of the resting bar.[4] He moved his machine forward by pushing on the ground with his feet, which were suitably protected by iron toe caps worn on his shoes (Croon, 1939; McGonagle, 1968; Lessing, 1990).

On 12 January 1818 Drais acquired a Baden patent with a validity of ten years for his invention. He built and sold quite a number of "running machines." Unofficially his Draisienne, as he liked to call it after its demonstration in Paris, was recognized as a road vehicle: On Saxon road signs it was placed under the rubric of *Fuhrwerke* ("machine for moving"). Probably to demonstrate its military usefulness, Drais drove his Draisienne from Karlsruhe to the French border in the short time of four hours. In other races against the clock he showed that he could drive significantly faster than a stagecoach (Klinckowstroem, 1959; Croon, 1939).

Figure 2.3
The "running machine" or "Draisienne," constructed by Karl Drais von Sauerbronn in 1817. The photo shows a colored lithograph of the inventor on his machine, probably published in the *Weimarian Journal for Literature, Art and Fashion* in 1820, with the caption "Der Freiherr von Drais. Inventor of the fast-running machine. Known fast and sharp thinker." The technical details of the lithograph are correct in every aspect. The poplars in the background are reminiscent of those on the road to Schwetzingen, the hills belong to the Odenwalt mountains. (I am grateful to Prof. H. E. Lessing for offering me this picture as well as its interpretation. See Lessing (1990) for a richly illustrated history of von Drais's machine. Photograph courtesy of the Städt. Reiss-Museum, Mannheim.)

In the beginning, press comments were positive. The German post adopted a few machines for its postmen (Rauck et al., 1979). Drais tried to establish a manufacturing firm, but this venture did not take off. Then the auditor's office prevented the German post from buying more Draisiennes because of the wear on the postmen's shoes (Rauck et al., 1979). The Draisienne became an object of ridicule for caricaturists, pedestrians, and schoolboys. Drais himself, running into an English horseman who poked fun at the machine and its rider, started an argument that ended in a fight. By the end of the 1840s his situation was rapidly deteriorating, both socially and psychologically, probably because of inherited epilepsy (Lessing, 1990). It is reported that when he drove past the city hall in Karlsruhe, he was often invited by the sentry to drink a pint of beer; in return, he had to ride down the stairs in front of the hall on his Draisienne, which often resulted in a kind of "salto portale." Drais died, poor and disillusioned, in Karlsruhe on 10 December 1851 (Croon, 1939).

In other countries, notably England, the Draisienne had more success. Dineur in France, Johnson in England, and Clarkson in the United States had, in the name of Drais, taken out patents on the invention in 1818 and 1819. Denis Johnson in particular tried hard to stimulate the use of what he liked to call the "pedestrian curricle" in England. The machine became commonly known as the hobbyhorse or dandyhorse. He developed a version for women in 1819, and in 1820 he organized an experiment of employing hobbyhorses for postmen. In America as in England, several "riding schools" were established. Hundreds of hobbyhorses were produced and sold. But it appeared to be only a craze. The new sport seems to have been vaguely irritating to the general public, perhaps because the riders used the best footpaths, perhaps because they just looked silly. Going downhill was a thrill, but without brakes it was quite dangerous, and it was hard to be graceful when you had no place to rest your feet. A well-known joke was that users of the hobbyhorse could ride in their carriage and walk in the mud at the same time. Moreover, blacksmiths and veterinarians saw a direct economic threat in the vehicle. Blacksmiths are reported to have smashed hobbyhorses that passed through their villages. This horse, they pointed out, required no shoeing (Woodforde, 1970).

The lack of comfort posed another problem for many users. The wooden or iron-clad wheels, the rigid frame, and the potholed roads resulted in a rough ride. Moreover, the movement of the body, shifting over and bumping up and down in the saddle, caused strains and not a few hernias. Another problem was that steering—the key trick in the "craft" of riding a modern bicycle—could hardly be used to keep the rider's balance.[5] When one looks closely at the Draisienne, it becomes obvious that steering must have taken a lot of force: The friction of the crossbar sliding under the frame backbone was quite great because the turning point of the front fork was positioned relatively far forward. You had to use your feet to balance the vehicle while also using them to give the Draisienne its forward momentum.

The problems of the hobbyhorse were recognized by users at the time, but Drais had not wanted to revise his machine fundamentally once he had provided the extra steering handle. (Occasionally he did provide extras such as brakes and saddles whose height could be adjusted.) Others, however, did try to find solutions to the more fundamental problems and thus improve the hobbyhorse. Johnson, for example, constructed an iron version of the machine, and this enabled him to improve the bearing of the steering axis. With such a tube bearing, the axis of the steering front wheel could be positioned more precisely and the friction created by turning the wheel could be greatly reduced, so that the steering mechanism could be used to keep the vehicle upright. Indeed, this has remained the most effective way to do so ever since. In retrospect, we realize that this development raised in principle the possibility of getting one's feet up off the ground and keeping one's balance by steering. However, the problem of muddy feet stayed unresolved for some decades.

Several methods were tried to raise the feet off the ground. As early as 1839, Kirkpatrick MacMillan, blacksmith of Courthill, Dumfriesshire, Scotland, added cranks to the rear wheel of his hobbyhorse (see figure 2.4). These cranks were driven by a forward and backward motion of the feet on two long treadles. The machine seems to have functioned quite well, although MacMillan is said to have caused the first bicycle road accident in 1842 by knocking over a child in the crowd cheering his entry into Glasgow; he was arrested and fined five shillings. He had designed the treadles so that they could be adapted to the leg length of various riders. Nevertheless, there is no record of his selling this hobbyhorse (Robertson, 1974).

Another revision of the "running machine" took the form of cranks attached to the front wheel. These cranks were usually pushed by the feet, thus enabling the rider to sit in his carriage without walking in the mud. Several people made this addition, probably independently of one another: for example, Gottlieb Mylius in Themar (Sachsen-Meiningen,

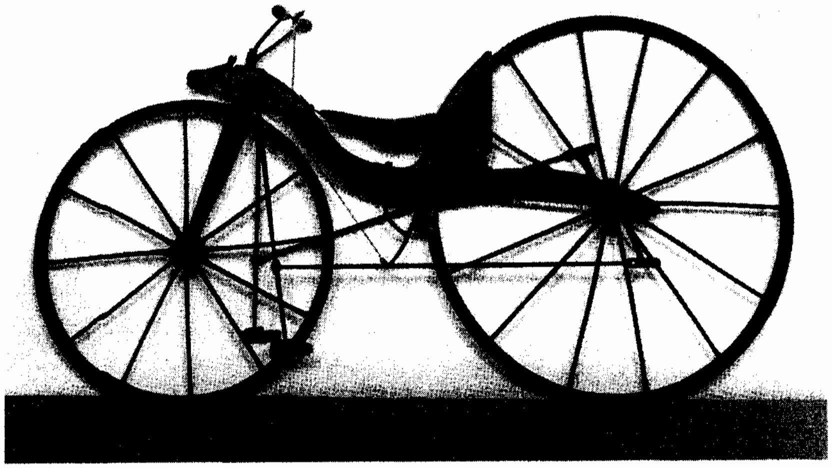

Figure 2.4
Kirckpatrick Macmillan constructed cranks with treadles to drive his "hobby-horse" (1839). The feet still made a walking movement. Photograph courtesy of the Trustees of the Science Museum, London.

Germany) in 1845, Philipp Moritz Fischer in Oberndorf (Germany) in 1853, Joseph Baader in Munich (Germany) in 1862. Lewis Gompertz in Britain constructed cranks for the front wheel that had to be moved by the rider's hands; the "feet in the mud" problem of course remained, but he may still have thought that his feet were needed for balancing (Croon, 1939; Feldhaus, 1914; Klinckowstroem, 1959; Rauck et al., 1979). In the late 1860s, as I will show, several inventors constructed rear-driven velocipedes as well—most of them probably not knowing about MacMillan's hobbyhorse. In summary, the 1860s seem to have been filled with numerous, and widely varying, designs of improved Draisiennes. Only one of them, built by Pierre Michaux, became a commercial success.

In 1861 Michaux, a coach builder in Paris, was asked to repair a Draisienne. One story is that his son Ernest, after testing it, complained about the great effort required to ride the machine and that, subsequently, he and his father designed the front-driven velocipede. The other story is that Pierre Lallement, employed in the Michaux workshop, first constructed such a front-driven Draisienne; he then went to America and left the honor to Michaux. In any case, Michaux continued to improve this velocipede and on 24 April 1868, a French patent was issued to him. The prototypes were made of wood, but by 1866 he had started

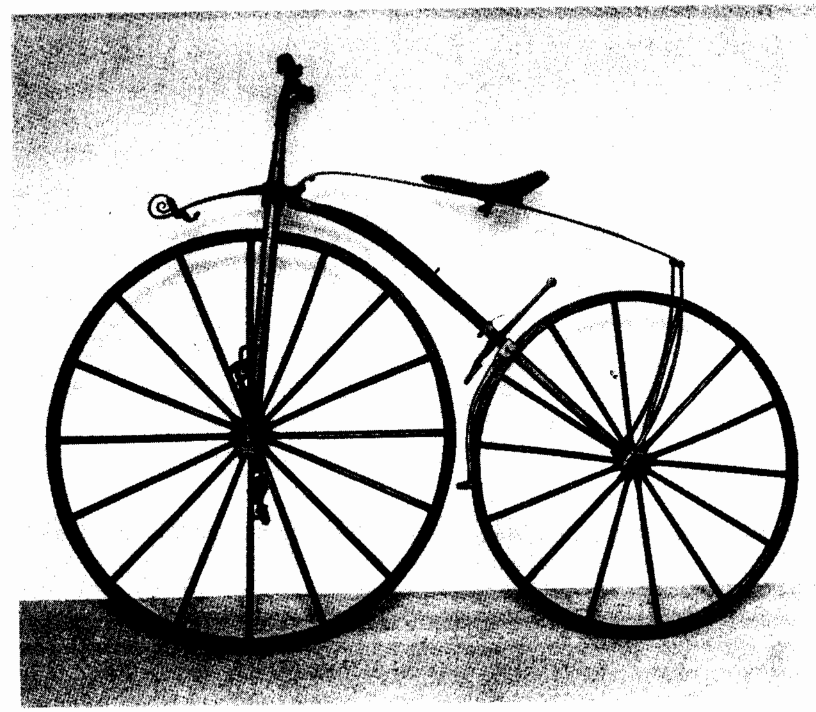

Figure 2.5
The vélocipède constructed by Pierre Michaux in about 1865. Photograph courtesy of the Trustees of the Science Museum, London.

to use iron. His machines were made with front wheels of various diameters (80, 90, and 100 cm) and a smaller rear wheel (see figure 2.5). The cranks had slotted ends so that their radius might be adapted to the length of the rider's legs. The frame was a solid wrought-iron bar with a fork for the rear wheel. A socket at its front end embraced the head of the driving wheel fork, to the top of which the steering handle was fitted. A brake block acting on the rear wheel could be applied by tightening a cord tied around the handlebar. He had also found a solution for the vibration problem: by making the rear wheel smaller, he obtained enough space to position the saddle on a spring brace. The saddle could be moved forward and backward along that spring to adjust to the rider's height. Leg rests were provided for coasting and a step for mounting (Caunter, 1958).

In the meantime, Pierre Lallement had received an American patent on his machine in 1866 and founded a business, but he could not cope with the rapidly increasing competition. The Hanlon brothers, a popular acrobat duo in New York City, were granted a patent on 7 July 1868, in which they suggested the use of rubber rings around the wheels to make them noiseless and to prevent slipping. The Hanlon brothers patented several other small improvements, most of which could be found on the Michaux velocipedes as well. Immediately after the Lallement patent, Americans did not pay much attention to the velocipede, but the Hanlon brothers' activities aroused much interest. December 1868 is identified as the moment at which there began a sudden wild enthusiasm for the Boneshaker, as the velocipede came to be known. Carriage makers commenced to produce the Boneshaker, which became very popular, especially among Harvard and Yale students. Riding schools with such names as "Amphicyclotheatrus" and "Gymnocyclidium" were established. Initially, the Boneshakers were priced at around $125, but soon models could be bought for around $75. The craze died as suddenly as it had started: in August 1869 the machines could be bought for some $12. There was one obvious problem related to the construction of the velocipede: the tendency to push one's body backward and away from the pedals when the going became heavy and more force was needed. The vibration problem also became serious, especially when cities began to pass ordinances against riding on the (smooth) pedestrian walks, thereby condemning the velocipede to the rough road—reminding its users of the origin of the name Boneshaker (Oliver and Berkebile 1974). Lallement returned to France.

In France, Michaux's business was prospering. Already in 1865 his workshop produced 400 velocipedes a year. During the 1867 World's Fair in Paris, he was so effective in promoting his machine that in the months afterward he could not respond in time to all orders he received. The firm decided to deliver velocipedes to the most prominent customers first. This in turn had quite a promotional effect; when the Imperial Prince Louis Napoleon and his friend the Duke of Alba were seen riding Michaux velocipedes, this provided one of the best and surely the cheapest promotion one could imagine. In 1869 the Michaux assembly moved to a new plant, where 500 workers were employed and about 200 velocipedes were produced each day. In England and Germany, the Michaux velocipede was not noticed until about 1867, when it was exhibited at the Paris World's Fair. In 1869 the first English and German designs were marketed. The Franco-German War of 1870–71 halted further development of the velocipede in France and Germany, and the lead was passed to the English (Rauck et al., 1979).

Side slipping, which was not so prominent with the hobbyhorse, was one of the major problems of the velocipede. It is difficult to imagine the skill involved in riding the velocipede: one had to continually adjust one's hold on the handlebar against the tendency of the front wheel to change direction with each thrust on the pedals (Minck, 1968; Woodforde, 1970). Those thrusts, in combination with the turning of the front wheel, made the velocipede frequently subject to side slipping because of its broad, flat, iron-shod wheels.

Before I move on to discuss further developments on the other side of the channel, it is worth noting that only by using commercial criteria can we attribute to Michaux the kind of prominence in the history of the bicycle that he has garnered. Application of either the "who was first" or the "who made the best" criterior would yield different answers. Other inventors were either earlier with their advances or closer to what would later become the bicycle design now considered the "best working machine." Mylius, Fischer, and Baader, who all constructed velocipedes with front-wheel drive, have been mentioned already. More interesting still, several other designs incorporated rear-wheel drive. Because these necessarily involved some mechanical means of transmitting the movement of the feet to the wheel, whether using gears, cranks, or treadles, most of them made it possible to incorporate some "amplification factor" in this movement. This applies to MacMillan's hobbyhorse and to Thomas McCall's similar machine; but also to the machine that was supposedly built in 1869 by André Guilmet and Meyer & Cie. Such an amplification factor would, if fully realized, have made the detour of the high-wheeler unnecessary.

Michaux had continued to modify his velocipede models. The last models, exhibited at the World's Fair, were distinctly lighter and had higher front wheels than the earliest models. The back wheel was kept relatively small. The handlebar was broader to help in controlling the side-to-side movement of the front wheel (Woodforde, 1970). The trend of enlarging the front wheel continued after the center of innovation had moved to England. This trend was further enhanced by the increasing focus on sports and racing as a context for riding the velocipede. One of the first velocipede races was held in May 1868 in St. Cloud, over 1,200 meters. In November 1869 an eighty-three-mile race from Paris to Rouen was held with two hundred participants, including five women. In England the sporting context was further emphasized, which had implications for the design of the bicycle. Because the pedals were fixed to the front wheel without any gearing system, the only way to realize a greater translational speed over the ground while maintaining the same angular velocity of your feet, rotating the wheel, was to increase the diameter of the front wheel. And this is exactly what happened.

At the end of the 1860s, the scene shifted to England completely. The hobbyhorse craze had not lasted, and people had almost forgotten about riding on two wheels when young Rowley Turner brought a Michaux velocipede back to Coventry after visiting the World's Fair in Paris in 1867. Turner, the Paris agent of the Coventry Sewing Machine Cy. Ltd., convinced his uncle Josiah Turner, manager of the company, to accept an order for manufacturing 400 velocipedes for export to France. However, the France-German War of 1870–71 made business with the continent difficult, and the order could not be filled. So, more was needed to get the bicycle industry going. Rowley Turner is reported to have escaped from the besieged city of Paris on his velocipede, after the last train had left (Williamson, 1966: 48). Safely back in England, he was quite energetic in promoting the velocipede, and the sewing machine company trimmed its sails to the new wind. Thus Coventry became one of the centers of the British cycle industry (Grew, 1921; Woodforde, 1970). In the next section I will follow more closely the shaping of this social group of manufacturers.

An important step toward increasing the wheel diameter was the application of wire spokes under tension instead of rigid spokes acting as struts. This enabled the manufacturers to keep the wheels relatively light while making them bigger. This improvement was patented in 1869 by W. F. Reynolds and J. A. Mays in their "Phantom" bicycle (Caunter, 1958). In the same year, the term "bicycle" was introduced in a British patent granted to J. I. Stassen, and thereafter it quickly replaced all other names (Palmer, 1958). In 1870 the bicycle "Ariel" was patented by James Starley and William Hillman (see also figure 2.6). The difference between this vehicle and the Michaux velocipede is striking: where the two wheels of the velocipede were indeed a little different in size, on the Ariel a man was "hurtling through space on one high wheel with another tiny wheel wobbling helplessly behind" (Thompson, 1941: 18). Generally speaking, this was the first lightweight all-metal bicycle, setting the stage for what would become known as the "high-wheeled Ordinary bicycle," or "Ordinary" for short.[6]

2.3 Social Groups and the Development of the Ordinary

The high-wheeled bicycle did not have one unambiguous meaning, but was evaluated in varied ways by different social groups. To describe

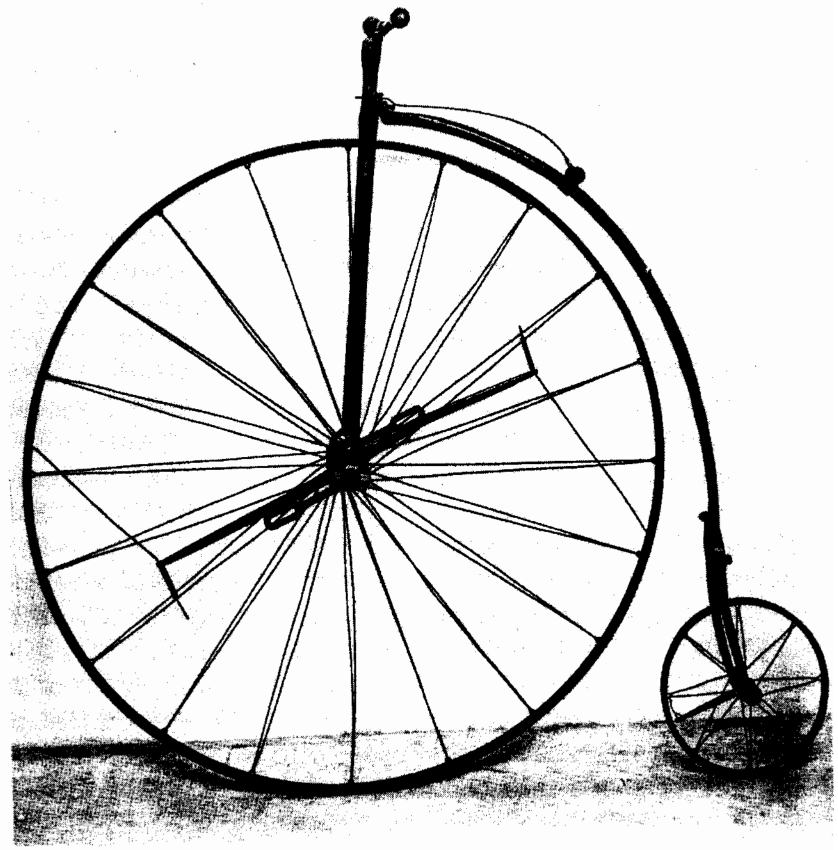

Figure 2.6
The "Ariel," patented in 1870 by J. Starley and W. Hillman, is generally considered to be the first high-wheeled "Ordinary bicycle." The lever to rotate the hub with respect to the rim and thereby increasing the tension of the spokes can be clearly seen. Photograph courtesy of the Trustees of the Science Museum, London.

its development, I will concentrate in this section on the various social groups involved—in its production and use, as well as in criticizing and fighting it. These groups will be described in some detail, and at the same time I will further trace the development of the high-wheeled bicycle. Let us first return to the story of Rowley Turner and the Coventry Sewing Machine Cy. Ltd., and examine the social group of producers.

The Bicycle Producers

The Coventry Sewing Machine Cy. Ltd. changed its name to Coventry Machinists Co., Ltd. in 1869 when it embarked, as Rowley Turner had suggested, on the manufacturing of velocipedes. Such a change of production was quite common in those days, in part because the Franco-German War had a destabilizing effect on British industry. As export opportunities grew scarce, several machine manufacturers started looking for other trades. Weapon makers, sewing machine manufacturers, and agricultural machine producers were only too happy to shift their production to bicycles (see figure 2.7). It is significant that at this stage of velocipede development the machine industry enters the story. Until the late 1860s, the basic skills needed to make a velocipede were those of the carriage builder: working with cast iron, making long bow springs for saddles, bending steel rims, and constructing wooden wheels—this was all well within his trade. But tubular backbones, wire spokes, more sophisticated bearings, special stampings and castings—that was quite another business (Grew, 1921: 27).

Figure 2.7
Not only sewing machine manufacturers but even weapons makers turned to cycle production (part of advertisement reprinted in Grew (1921))

To understand this development better, I will briefly go back in history to sketch the founding of the Coventry Machinists Co. and the role of James Starley, often called in England the "Father of the Cycle Industry." Starley ran away from his Sussex home because he hated farming and wanted to be a mechanical inventor. He was subsequently employed as gardener in a large household. During this period he made several successful contraptions—for example, for use in the garden. One of his more colorful inventions, a "self-rocking basinette," was dropped when the prototype made a young child violently ill by rocking a bit too effectively (Williamson, 1966: 27). Starley repaired watches and clocks in the evening and thus educated himself about the basics of fine machine construction. Then one day he was asked to repair the sewing machine of the lady of the house. At that time a sewing machine was an expensive novelty that not many could afford, and it represented the most complicated mechanism that Starley had ever handled. He took the risk of stripping down the entire machine. He spotted the trouble (a tiny screw had worked loose), reconstructed the machine, and made it run better than ever. This impressed starley's employer so that he persuaded his friend Josiah Turner, manager of the company that was the actual maker of this particular machine, to take on Starley as an employee of the London factory of Nelson, Wilson & Co. (Williamson, 1966: 33).

Turner quickly identified Starley as "a sort of mechanical genius." He helped him to take out a patent on a treadle arrangement that kept the sewing machine running while its operator's hands were free to guide the cloth. By this time Turner had such faith in Starley's technical capabilities that he proposed that they leave the London firm and start a new company together to exploit this invention. They did so, moved to Coventry, and founded the Coventry Sewing Machine Cy. in 1861 (Williamson, 1966: 36–37). Turner recruited other technicians from the London region as well: Thomas Bayliss, William Hillman, and George Singer, to name a few (Grew, 1921: 2; Williamson, 1966: 41). In Coventry they found a receptive atmosphere. To highlight the particular combination of unemployment in technically skilled and unskilled labor, I shall briefly review the economic circumstances of this county.

The Warwickshire city of Coventry was economically and socially in bad shape. The weaving industry had been weakened by a decade of social conflicts between workers and employers. The long conflict, instigated partly by the tariff policies of the national government and partly be class struggle, almost ruined the ribbon weaving industry. Of the original eighty weaving masters existing befare 1855, only twenty remained by 1865; there had been at least fifty bankruptcies. Unemployment was very high in Coventry. Poverty spread, and so many families were threatened by starvation that a national appeal was launched in the early 1860s (Williamson, 1966: 38–40). From the census reports of 1861 and 1871, a remarkable decrease of the population of Coventry can be traced, especially when these figures are seen in the perspective of the population growth in other towns in the Midlands.[7] The watchmaking industry, which had been expanding between 1830 and 1860, had declined as well, although for other reasons. Coventry watchmakers did not have factories, and the individual masters in their isolated workshops were not able to compete with the cheaper machine-produced products imported from America and Switzerland (Williamson, 1966: 40). Despite the displacement of people from Coventry, the new sewing machine company still found many skilled workers. For Coventry this meant the beginning of its development into an engineering city. The watch trade provided the nucleus of skilled labor, and the ribbon trade the pool of unskilled labor, with which Coventry would graduate from the sewing machine and the bicycle to the motor bicycle and the motorcar, climbing back toward prosperity as the nineteenth century drew to a close (Prest, 1960: x).

The Coventry Sewing Machine Cy. prospered to such an extent that larger premises were necessary after seven years. The company had continuously improved its sewing machines by adding innovations and turning out new models with names such as "The European," "Godiva," "Express," and "Swiftsure." When Rowley Turner convinced his uncle Josiah to start making velocipedes, the new product was approached in the same innovative spirit (Williamson, 1966: 41). Starley's immediate reaction when confronted with the new machine was to lift the velocipede and criticize it for being weighty and cumbersome (Williamson, 1966: 48). Starley learned to ride the machine, however, and he quickly thought of a series of small but important modifications. For example, he fitted a small step to the hub of the rear wheel to enable the rider to simply step on. The usual way of mounting a velocipede was to take a short run and leap into the saddle. Some of these modifications probably have been incorporated in the first velocipedes produced by the Coventry Machinists Co., but there are no records of these early products.

Starley and Hillman then concentrated on designing a new, light velocipede. As sewing machine constructors rather than carriage builders, they employed quite different techniques than had Michaux. For one thing, there were no wooden parts on their machine. They followed Reynolds and Mays by using wire spokes under tension to make the wheels without heavy struts (made of wood or, later, hollow steel tubes) loaded by pressure forces. But added to this was a mechanism to tighten these radially positioned spokes and thus stiffen the wheels, which in Reynolds's and Mays's case still lacked rigidity. This was done by fixing two levers to the middle of the hub; the levers were connected by wires to opposite positions on the rim. By tightening these wires, one could make the rim turn relative to the hub until the spokes had the required tension (Caunter, 1958: 6). Finally, they followed the trend of enlarging the front wheel. Thus Starley and Hillman patented the Ariel on 11 August 1870 (see figure 2.6). They had such a confidence in their new product that they left the Coventry Machinists Co. and started a new business (Williamson, 1966: 49). Almost at the same time, W. H. J. Grout took out a patent on his "Grout Tension Bicycle" (Grout, 1870). This patent added some further basic elements to the scheme of a high-wheeled bicycle, notably the hollow front fork that further reduced the frame's weight, massive rubber tires, and a new means of mounting the spokes. Grout's radial spokes were threaded into nipples loosely riveted into the rim, which could be used to adjust the tension of the spokes and thus to true the wheel by screwing them on and off the spokes. These two patents can be said to have laid the basic pattern of the high-wheeled bicycle in the early 1870s.

Of course Turner, Starley, and the other Coventry Machinists Co. men were not alone in identifying the velocipede as an attractive new line of manufacture. The city of Coventry soon saw a variety of former watchmakers, ships' engineers, cutlery shop workers, and gun makers starting small workshops in which to build velocipedes.[8] In other towns, such as Leicester and Liverpool, velocipede makers were commencing business as well. Coventry was not a manufacturing town, however, as was Birmingham; thus in search of suitable materials, the Coventry engineers had to turn elsewhere. For example, Sheffield provided bar steel for bearings and wire for spokes; Walsall supplied saddles; springs came from Redditch and Sheffield; Birmingham firms provided the drawn steel tubes crucial to making those light metal frames, and it supplied the steel balls for bearings (Grew, 1921: 27). The assistance of Birmingham was not without risk for Coventry. Although at first the firms in Birmingham produced only half-finished materials and velocipede parts, they started to look around for outlets for their production in slack times.

For example, Perry & Co., pen makers, and the Birmingham Small Arms Co. (B.S.A.) began to supply sets of fittings and parts for small workshops, which were in this way able to build velocipedes without requiring the more expensive tools and machinery (Grew, 1921: 29–30). However, making good parts is not the same as making good bicycles, and Coventry remained the center of the British cycle industry for a long time. In the 1870s and 1880s the industry spread all over the Midlands, Yorkshire, and part of London.

Starley and Hillman did not immediately market their Ariel, but first produced and sold velocipedes in which they incorporated many of Starley's improvements. Hillman suggested that the launching of the high-wheeled bicycle had to be marked by a spectacular promotional feat. They decided to set up a kind of unusual test: completing the ride from London to Coventry in one day. And they did, probably in 1871.[9] Both gentlemen took their bicycles to Euston Station on the train, spent the night in the station hotel and got up before daylight. They had a light breakfast and started out along the cobbled roads of London. Once outside the city the roads became better, and at about 8:30 A.M. they reached St. Albans, where they stopped to have an ample breakfast. The next stretch ran over the Chiltern Hills. On some of the steeper hills they had to walk, but compensation came on the long downhill portions where speeds of some twelve miles an hour were attained. "Disaster might have overtaken the gentlemen who wished to take full advantage of the hills, had it not been for Mr. Starley's ingenious brake." By one o'clock the riders had covered about half the distance, and they enjoyed dinner and an hour of rest near Bletchley. Mounted again, they were cheered or by the inhabitants of towns and villages, few of whom had seen a bicycle before. Only one mishap befell them. "Mr. Hillman was thrown from his machine when the rubber tyre of his front wheel came off but escaped with nothing worse than a grazed hand. He was able to bind the tyre on again and proceed without further trouble." The last miles from Daventry to Coventry were hard. The men were tired and the darkness made it difficult to avoid stones and holes in the road. But just when the clock of St. Michael's struck midnight, it is said, they reached Starley's residence in Coventry. The ninety-six miles had been completed within one day and with the bicycles still in almost perfect condition. The contemporary account finishes by stating that "the bicycle that has been developed by Messrs. Starley and Hillman from the velocipede is a most efficient form of human transport. It may be recorded that the two intrepid gentlemen, though tired, and stiff after their long ride, were no worse for their adventure." However, an intimate footnote was added in the margin of this account that for both riders the experience was painful enough to oblige them to remain in their beds "for two or three days." When, subsequently, the Ariel was marketed in September 1871, it was priced at £8 (Williamson, 1966: 54).

So they were quite active, these bicycle producers. But for whom were they producing? For whom was the Ariel's spectacular promotion intended? The demand increased. By the end of the 1870s clubs and associations for cyclists had been established in most countries. To continue the story of the high-wheeled Ordinary bicycle, we will now shift our focus to its users.

The Ordinary Users

The memorable ride of Starley and Hillman enhanced the image of the new high-wheeled bicycle as a sport machine, and records were set and contested on all classic roads of England. For example, the Brighton Road is associated with the earliest bicycle performances, as is Watling Street, on which Starley and Hillman crossed the Chiltern Hills. Especially on the Brighton Road, relay rides were often held against the four-horse coach (Grew, 1921: 78). Track racing started soon as well. Probably the first was in 1869 in Crystal Palace, London (Woodforde, 1970: 161), but other tracks sprang up in Birmingham, Wolverhampton, and Leicester (Grew, 1921: 67–68). After the Franco-German War, racing on Ordinaries began on the continent as well.[10] Because the German local ordinances were rather limiting—for example, restricting racing on public roads to the early morning and late evening hours—in Germany the bicycle clubs started to build separate racing courses.[11] We will come back to bicycle racing below, for often there was more at stake than just a medal and a small cash prize.

Whereas skiing began as a way of getting about and evolved into a sport, bicycling began as a sport activity and evolved into a means of transport. Even when the rider of a high-wheeled bicycle was not actually racing, he viewed his activity primarily as an athletic pastime. It was not easy to mount the high-wheeled bicycle, even with the provision of a step directly above the trail wheel. Uwe Timm (1984: 17–22) gives a convincing and colorful description of his uncle Franz Schröder's efforts to learn how to ride high-wheeled bicycle: "Schröder experienced this afternoon the large and fundamental difference between theory and practice. He mounted and fell down. The crowd of spectators was standing there and kept silent. He stood up again and fell off again."[12] He repeated this motion several times, to increasingly enthusiastic clapping and cheering: "Hopf, hopf, hopf, immer aufem Kopf!"[13] By the end of the afternoon he had learned how to mount and ride in a straight line; making a curve and dismounting were not yet in his repertoire, so each little ride ended in a fall. However, after another week of trying (in which he lost two finger tips between the spokes of the front wheel), he had mastered the art of riding a high-wheeled bicycle. No wonder bicyclists wore an anxious air. "Bicyclist's face," this expression was called, and newspapers predicted a generation with hunchbacks and tortured faces as a result of the bicycle craze (Thompson, 1941: 18). Going head-over-heels was quite common, as we will see shortly. Partly for that reason, and because there was no freewheel mechanism—which implied that the cranks were permanently turning around when riding—a special mode of riding was practiced when moving downhill. This "coasting" again required some athletic ability: when the bicycle was moving fast, the legs were thrown over the handlebar to the front (see figure 2.8).

Learning to ride a bicycle became a serious business in the 1870s. In some European cities, bicyclists had to pass an examination to prove their proficiency (Woodforde, 1970: 120). Bicycle schools existed in most towns of some importance. Partly this was made necessary by the maturity of the riders, none of whom had learned cycling as a child, which is now the usual way, at least in bicycling countries.[14] On the other hand, the bicycles of those days were definitely more difficult to ride than are modern versions. Even walking a bicycle could result in a bruised leg when the novice had not yet learned how to keep free of the revolving pedals.

Charles Spencer, owner of the London gymnasium bicycling school, described in his instruction book how to mount a high-wheeled Ordinary:

> Hold the handle with the left hand and place the other on the seat. Now take a few running steps, and when the right foot is on the ground give a hop with that foot, and at the same time place the left foot on the step, throwing your right leg over on to the seat. Nothing but a good running hop will give you time to adjust your toe on the step as it is moving. It requires, I need not say, a certain amount of strength and agility.[15]

The cycling schools and instruction books tried to make the art of bicycling as explicit as possible. For example, what

> each learner must remember is simply to turn the handles in the direction in which he is falling. Having drummed this into his head, the rest is easy. He will soon discover that there is a happy medium and that the bars require only to be turned slightly, and instantly brought back to the straight as soon as the machine has resumed the perpendicular.[16]

Figure 2.8
The first rider has thrown his legs over the handlebar when coasting downhill.

It is unlikely that a modern bicyclist would be able to describe so adequately what exactly she is doing when keeping her balance. Her craft of riding a bicycle is almost completely "tacit knowledge." However, riding the high-wheeler could be just as pleasant and comfortable as it was dangerous. Having mounted an ordinary bicycle—by this time implicitly meaning a high-wheeler—one would immediately feel its easy-rolling, billowy motion as very different from the bone-shaking effect of the velocipede.[17] Moreover, the pedals almost directly beneath the saddle enabled one to sit comfortably upright, with the bar in one's lap; on the velocipede, there had always been the pushing forward of the legs and the pulling on the handlebar to compensate for that pushing. There was a direct advantage of being so high above the ground: the roads had worsened since the railways eclipsed the horse coach, and the large wheel could keep its rider well above the water-filled holes and mud, while dealing effectively with the bumps.

Few men over middle age, and even fewer women, attempted to ride the high-wheeled bicycle. The typical bicyclist—by this time meaning an Ordinary rider—had to be young, athletic, and well-to-do. Accordingly, bicycling still had, as in the early days of the hobbyhorse, an element of showing off:

> Bicycle riding, like skating, combines the pleasure of personal display with the luxury of swift motion through the air. The pursuit admits, too, of ostentation, as the machine can be adorned with almost any degree of visible luxury; and differences of price, and, so to speak, of caste in the vehicle, can be made as apparent as in a carriage. It is not wonderful, therefore, that idle men sprang to the idea.[18]

Generally, bicycling was associated with progress and modern times. This was sometimes voiced in grandiose terms:

> The bicycle: the awakening of a new era. The town comes into the village, the village comes into the town, the separation comes to an end, town and village merge more and more. Cyclisation: the era of the bicycle, that is the new time with richer, broader and more mobile civilisation, a back to nature which however keeps all advantages of culture.[19]

But cycling was also linked with new social movements in more concrete ways. The first meeting of the bicycle society of the town of Coburg was observed by a local police officer, who had to ensure that this society was not an undercover meeting of the forbidden social democratic party. Schröder's wife Anna was pointed out for committing subversive actions that were intuitively understood as revolutionary and the first exemplification of the women's movement in Coburg. "*Petroleuse* on a high-wheeler" read the headline in the local newspaper, thus associating female bicyclists with *petroleuses* of the 1871 *Commune.*[20] And especially in the days of the low-wheeler, after the high-wheeled bicycle had become obsolete, cycling was explicitly linked to feminism. I shall return to this point. For an instrument of the liberation of the proletariat, the bicycle was too expensive. The laborer who would have liked to use the machine for his transportation to work could not afford one, until a second-hand market had developed.[21] Indeed, many workers were still riding their

high-wheeler after 1900; by that time it had been nicknamed "Penny-farthing" because it was not "ordinary" any more. In Ashford, Kent, a gas lamp lighter still used it in 1914, finding it useful in his work (Woodforde, 1970: 49).

The Nonusers of the Ordinary

With only the group of "young men of means and nerve" riding the Ordinary, there were many more people not using it. Some of them wanted to ride a bicycle but could not afford one, or were not physically able to mount the high-wheeler, while others actively opposed the machine.

There were several reasons for the antagonism against bicyclists. One was irritation caused by the evident satisfaction with which the riders of the high-wheeler elevated themselves above their fellow citizens. This irritation gave rise to derisive cheers such as "Monkey on a gridiron!" (Wells, 1896: 24) or the loudly hailed pronouncement that "your wheel is going round!" (Woodforde, 1970: 50). Jokes like this inflicted no injury, "but when to words are added deeds, and stones are thrown, sticks thrust into the wheels, or caps hurled into the machinery, the picture has a different aspect."[22] The touring clergyman who made this observation added, "All the above in certain districts are of common occurrence, and have all happened to me, especially when passing through a village just after school is closed. The playful children just let loose from school are generally at this time in an excitable state of mind."[23]

Another reason for the antagonism was the threat posed by the bicyclists to those who were walking.

> Pedestrians backed almost into the hedges when they met one of them, for was there not almost every week in the Sunday newspaper the story of some one being knocked down and killed by a bicycle, and letters from readers saying cyclists ought not to be allowed to use the roads, which, as everybody knew, were provided for people to walk on or to drive on behind horses. "Bicyclists ought to have roads to themselves, like railway trains" was the general opinion. (Thompson, 1941: 18)

Police and magistrates supported this view. Local ordinances posed various restrictions on bicycling, often widely different in different towns. A German cantonal judge observed that these local ordinances stipulated many obligations for the cyclists, but hardly any rights.[24] Elaborating on these rights, he remarked that the offense bicyclists suffered from most frequently was defamation. Carriage drivers being overtaken by a bicycle, pedestrians having to wait a few seconds before crossing a street—

they all would shout insults at the cyclist. The judge described the various forms of defamation recognized in German law and added that the so-called *einfache Beleidigung* (simple slander), which could be exerted by words, gestures, or pawing, was most common. An enthusiastic bicyclist himself, he used to write down all insulting words shouted at him; he was amazed by the public's creativity. Newspaper reports about fights between bicyclists and pedestrians or coach drivers were quite common. A particularly flagrant attack, Woodforde reports, happened on 26 August 1876, when a coach driver lashed an overtaking bicyclist with his whip and the coach guard actually threw an iron ball, which he had secured to a rope, between the spokes of the wheel (Woodforde, 1970: 52). An offense with which bicyclists were frequently charged was "riding furiously," especially on roads with excellent wood paving such as the high road between Kensington and Hammersmith in London. The antagonism of the general public can be sensed through the following excerpt from a court hearing transcript, concerning four men charged with furious riding: "Police constable ZYX 4002 deposed that he was on duty the previous evening, and saw the defendants riding at a rate of forty miles an hour; he walked after them and overtook them ... taking them to the station handcuffed."[25] If we can assume that this speed of forty miles an hour was a gross overstatement, the acceptance of such a statement suggests a generally negative opinion about bicycling in those days.

There were also people who wanted to ride a bicycle but could not do so. One reason has been mentioned already: the price of the Ordinaries prevented middle-class and working-class people from buying a new machine. The other main reason was the problem of safety. This problem made older men and women reluctant to mount the high-wheeler. For women there was an additional problem, and I will turn to that first.

In 1900 it was still possible to find newspaper articles such as the following, reporting on the observation of a two-seater bicycle with a man and woman on it:

> The numerous public that was walking in the Maximilian-strasse, yesterday at noon, witnessed an irritating spectacle that gave rise to much indignation.... Unashamed, proud like an Amazon, the graceful lady displayed herself to men's eyes. We ask: Is this the newest form of bicycle sport? Is it possible that in this manner common decency is being hit in the face without punishment? Finally: is this the newest form of advertising for certain female persons? Where is the police?[26]

This must have been a rather exceptional outcry in 1900, especially as it concerned merely a low-wheeled two-seater. But it makes one think about the sentiments expressed two decades earlier against women wanting or actually trying to ride on high-wheeled bicycles. The whole weight of Victorian prudery set itself against women taking such a masculine and, on the high-wheeler, revealing posture.[27] Some bicycle producers tried to find a solution for what was euphemistically called "the dress problem." In 1874 Starley and Hillman pursued the idea of S. W. Thomas, patented in 1870, of having two pedals on one side of the velocipede, thus enabling it to be "side-ridden."[28] This is what Starley and Hillman did with their successful Ariel high-wheeler. The rider sat in a sidesaddle position, the handlebars being shortened on one side and lengthened on the other. The rear wheel was mounted on an overhung axle, and the front wheel was offset from the track of the rear wheel to counteract the bias of the sidesaddle posture (see figure 2.9). It all seems rather complicated, and the machine must have been quite difficult to master. This technical solution to the dress problem did not become a success, and few sidesaddle bicycles were sold.

However, solutions other than purely technical innovations were tried—and indeed, were more successful. First, Victorian morals could occasionally be a little more flexible than one might assume. For example, a young lady who wrote to a magazine in 1885 about having used a bicycle (which at that date must have been a high-wheeled Ordinary) was reassured in the reply: "The mere act of riding a bicycle is not in itself sinful, and if it is the only means of reaching the church on a Sunday, it may be excusable."[29] Another solution to the dress problem posed by the Ordinary was to modify the designs of women clothing and, accordingly, to set new standards of fashion. A third way for women to ride cycles while avoiding the Ordinary was to use tricycles.

The "safety problem" was pressing for many nonusers of the Ordinary. As mentioned, the Ordinary rider was liable to go head over heels when encountering a small obstacle like a stone, a hole in the road, or an animal wandering about. The trend of enlarging the front wheel of the velocipede had continued once speed had become so important, and this made it necessary to move the saddle forward in order to keep pedals within reach of the feet. This implied a reduction of the rear wheel's diameter—partly because otherwise the machine could not be mounted at all, partly to reduce the bicycle is weight, and partly for aesthetic reasons (it set off the grandeur of the high wheel). But these two developments moved the center of gravity of the bicycle and rider far forward, to

Figure 2.9
The ladies' model "Ariel" (to the right), designed in 1874 by J. Starley and W. Hillman. The pedals do not drive the cranks directly, but are placed at the ends of levers, pivoted some distance in front of and slightly above the front wheel axle on the left side of the bicycle. About halfway along these levers, short connecting-rods communicate the motion of the pedals to the overhung crank-shaft. The axle forming the pivot for the pedal levers is supported on the inside by an arm attached to the front fork and on the outside by a stay that joins the lower crosspiece of the steering head.

The lever to rotate the hub with respect to the rim and thereby increasing the tension of the spokes can also be seen in both bicycles. Photograph courtesy of the Trustees of the Science Museum, London.

a position almost directly above the turning point of the system. Thus only a very small counter force—for example, from the bumpiness of the road, but also from the sudden application of the brake—would topple the whole thing. Another serious and frequent cause of falls was getting a foot caught between the spokes, for example when feeling for the step before dismounting. Different ways of falling forward even got their own labels (as in present-day wind surfing), so that an experienced Ordinary rider remarked, "The manoeuvre is so common, that the peculiar form of tumble that ensues is known by the distinctive name of 'the cropper' or 'Imperial crowner.'"[30] Falls were such an accepted part of bicycling that producers advertised their bicycles' ability to withstand falls, rather than claiming that they did not fall at all. In the *Humber Bicycle Catalogue* of 1873, a letter from a customer is reproduced, saying that although his Humber bicycle "on several occasions [had] been engaged in universal spills and collisions, it is now almost as sound as when first despatched from your works."[31] This, however, was to change within a few years, when manufacturers began to regard women and older men as potential bicycle buyers.

2.4 Relevant Social Groups

In this section, the flow of the historical case study is halted for the first methodological intermezzo. The concept "relevant social group" will be introduced.

I have described the development of the Ordinary bicycle by tracing what various groups thought of it. I used these perspectives to avoid the pitfall of retrospective distortion. If we are to find out how the so-called detour of the high-wheeled bicycle came about, it seems wise to stick as closely as possible to the relevant actors, rather than bringing our own evaluations to bear on the story. Thus we may be able to show that what in a Whiggish account of bicycle history seemed a strange and ineffective detour was indeed quite straightforward when viewed from the actors' perspective. ("Whiggish" is an account that presents history as uninterrupted progress, implying that the present state of affairs follows necessarily from the previous.)

But there is another reason to focus on social groups than merely the desire to avoid retrospective distortion. One of the central claims in this book will be that such social groups are relevant for understanding the development of technology. I will first show how empirical research can identify the social groups that are *relevant for the actors.* Then I will argue that these social groups are also theoretically *relevant for the analyst* when he or she sets out to explain the development of technical change.

Empirical Research to Identify Relevant Social Groups

Relevant social groups may be identified and described by following two rules: "roll a snowball" and "follow the actors." The snowball method is used in contemporaneous sociological research, and I will use a study of a scientific controversy to illustrate this method.[32] Typically one starts by interviewing a limited number of actors (identified by reading the relevant literature) and asks them, at the end of each interview, who else should be interviewed to get a complete picture. In doing this with each interviewee, the number of new actors at first increases rapidly like a snowball, but after some time no new names will be mentioned—you have the complete set of actors involved in the controversy.[33] This is a neat methodological solution to the problem of how to delineate the group involved in a scientific controversy, at least when interviewing is a possible technique.

The same method is applicable in historical research. Just as we can find relevant actor by noting who is mentioned by other actors, we can identify what social groups are relevant with respect to a specific artifact by noting all social groups mentioned in relation to that artifact in historical documents (see figure 2.10). When after some time the researcher does not find reference to new groups, it is clear that all relevant social groups have been identified.

By using the snowball technique, a first list of relevant social groups can be made. Using this as a starting point, the researcher can then "follow the actors" to learn about the relevant social groups in more detail.[34] This can be quite a straightforward process: because these social groups are relevant for the actors themselves, they typically have described and delineated the groups adequately. Thus marketing people will identify user groups and describe them as far as is relevant; producers thus had identified rich, young, athletic men as bicyclists; and anticyclists had identified tricyclists and bicyclists. Thus after the first step of identifying the relevant social group, two subsequent steps were taken: a second to describe the relevant social groups in more detail, and a third to further identify the relevant social group by delineating it from other relevant social groups. In practice, these description steps are of course interdependent, and it is not practical to carry them out completely separately.

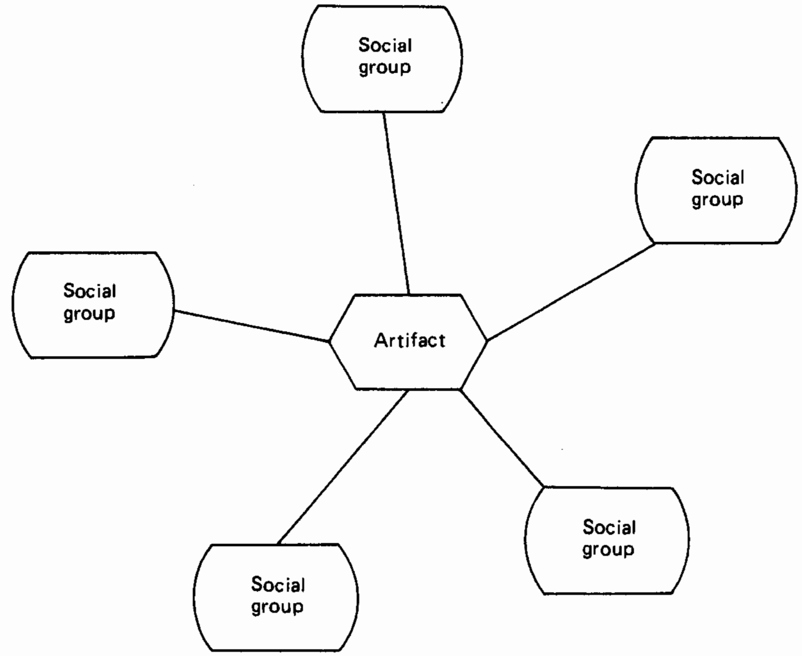

Figure 2.10
Related to an artifact, the relevant social groups are identified.

For example, the relevant social group of Ordinary users was characterized, in the first descriptive step, as being constituted of people who saw the Ordinary as a sporting machine that was rather hazardous to ride. In the second step this relevant social group was further described as consisting of young athletic men, distinctly upper and upper-middle class. A brief reference to road maintenance in the new railway era hinted at the wider socioeconomic context. The description of relevant social groups is as important as the detailed description of artifacts in standard technical histories. So I will, when turning to a discussion of tricycles, devote substantial space to women, postmen, and queens as well as to differential gears, big wheels, and brakes.

Then, for the third step, the relevant social groups' boundaries, intuitively assumed at the outset, are traced more precisely. Again, the actors can be followed. In the turmoil of technical development actors, to make sense of their world, will identify new relevant social groups or forget about others. Thus the boundaries of social groups, although once clear-cut, may become fuzzy; new groups may split off and old groups may merge into new ones. Actors thus "simplify" and reorder their world by forgetting about obsolete distinctions or by drawing new boundaries.[35] As I will show, at some point bicycle producers concluded, for example, that within the relevant social group of nonusers, women should be separated out as an important relevant social group. Similarly, the relevant social group of Ordinary users did not remain unchanged. At first it coincided completely with the group of cyclists. With the coming of the low-wheeled bicycle, some parts of the relevant social group of nonusers became users of the safety bicycle, and the relevant social group of Ordinary users changed accordingly. Its boundaries changed—some categories of cyclists switched from the high-wheeler to the safety. But its key characteristics changed as well: in the beginning its members could be labeled "young men of means and nerve," and Franz Schröder, a typical Ordinary rider, successively passed through the stages of being associated with social democracy and other "revolutionary" movements to being simply the laughingstock of town.

Relevant Social Groups: Also Relevant for the Analyst

The concept of "relevant social group" is an actor's category. Although actors generally do not use these words, they actively employ the concept to order their world. A crucial claim in the development of a social constructivist model of technology is, however, that "relevant social group" is also an important analyst's category. It will help us to describe the development of technical artifacts in terms that meet the requirements set out in the first chapter.

Technological development should be viewed as a social process, not an autonomous occurrence. In other words, relevant social groups will be the carriers of that process. Hence the world as it exists for these relevant social groups is a good place for the analyst to begin his or her research. Thus the analyst would be content to use "cyclists" as a relevant social group, but introduce separate "bicyclists" and "tricyclists" only when the actors themselves do so. The basic rationale for this strategy is that only when a social group is explicitly on the map somewhere does it make sense for the analyst to take it into account.

There seems to be one obvious problem with this argument, which has two important aspects, the political and the epistemological. The political aspect arises out of recognition that powerless social groups—those that do not have the ability to speak up and let themselves be found by the analyst—will thus be missing in the account. The epistemological aspect of the problem concerns the suggested identity between actors' and analysts' categories. The first formulation of the problem is relevant for the practical and political relevance of technology studies, to which I will return in the last chapter. The second formulation addresses a classic debate in the philosophy of the social sciences. This problem, however, does not need to exist, in either of the two formulations.

The problem of the "missing groups" does not exist if the conceptual framework I am developing is taken in the right spirit—as a collection of sensitizing concepts that aims to provide the researcher with a set of heuristics with which to study technological development. Another slightly rhetorical way of making the same point is to emphasize that the goal is to develop a framework for *scientific research,* not a computer program for an expert system to carry out social studies of technology. Let me give one example, comparing my treatment of the bicycle and the fluorescent lamp case studies. In the bicycle case I followed the lead of the actors and included the relevant social group of women in my description. In the fluorescent lamp case I did not, as will become clear in the fourth chapter. An expert system would have done so, however, because a General Electric manager once mentioned "the housewife" as a relevant social group. Another human researcher might have decided differently, and have included the relevant social group of housewives in her description—there is no way of deciding "mechanically" which of the two accounts would be best. This is where the approach outlined in this book draws most heavily on methods of interpretative research.

Similarly, no simple identity between actors' and researchers' categories is advocated. I am proposing the combined method of "snowballing" and "following the actors" as heuristics—a negative heuristic to avoid a facile projection of the analyst's own categories, which might lead to retrospective distortion and Whiggish accounts; and a positive heuristic to help identify relevant social group that do not figure in the standard histories of the specific technology. In the next chapter some concepts will be introduced that are exclusively analysts' categories.

What I have been arguing here about the identification, delineation, and description of relevant social groups also applies to the characterization of artifacts. If we want to understand the development of technology as a social process, it is crucial to take the artifacts as they are viewed by the relevant social groups. If we do otherwise, the technology again takes on an autonomous life of its own. Thus in this descriptive model the meanings attributed to the artifact by the different relevant social groups constitute the artifact. I described, for example, the artifact Ordinary bicycle "through the eyes" of members of the relevant social groups of women, older men, and Ordinary users. The definition of the Ordinary as a hazardous bicycle (for the relevant social groups of women and elderly men) was supplemented by listing specific ways of using the artifact, such as track and road racing, touring, and showing off in parks (for the Ordinary users). The risky aspects of riding the Ordinary were explicated by describing in some detail the techniques involved in mounting the machine and in coasting downhill. Also the pleasure and comfort of riding the Ordinary were described and contrasted with the bone-shaking experience of riding bicycles with smaller wheels.

As an aid in describing the meanings attributed by the relevant social groups to an artifact, I will now focus on the problems and solutions as seen by these relevant social groups.

2.5 Focus on Problems and Solutions

When my daughters want to find out about a ball, they do not sit down and stare at it. They pick it up, throw it against the wall, kick it, or play catch. When a physicist wants to study an atom, she excites it and studies the emission spectrum when electrons fall back into their lower energy states. When you want to study a social system—for example, the relationship of a married couple—not much would be learned by looking at it in steady state. Rather, it would help if you could induce a change—for example, by sending in a newborn child. Then insight might be gained about the hidden properties and processes that keep the social system together, or not.[36] This principle of focusing on disturbances when studying a system can be usefully employed when describing the meanings attributed by relevant social groups to an artifact.

Therefore in describing the artifacts I have tried to avoid the uninformative states of equilibrium and stability. Instead the focus was on the problems as seen by the various relevant social groups (see figure 2.11). Linked to each perceived problem is a smaller or larger set of possible solutions (see figure 2.12).

What kind of model is emerging? First, focusing on the different relevant social groups seems to be an effective way of guarding against the kind of implicit assumptions of linearity that I have criticized in the first chapter. From a traditional, quasi-linear view, the bicycle's history was depicted as a simple genealogy extending from Boneshaker to velocipede to high-wheeled Ordinary to Lawson's Bicyclette, the last labeled "the

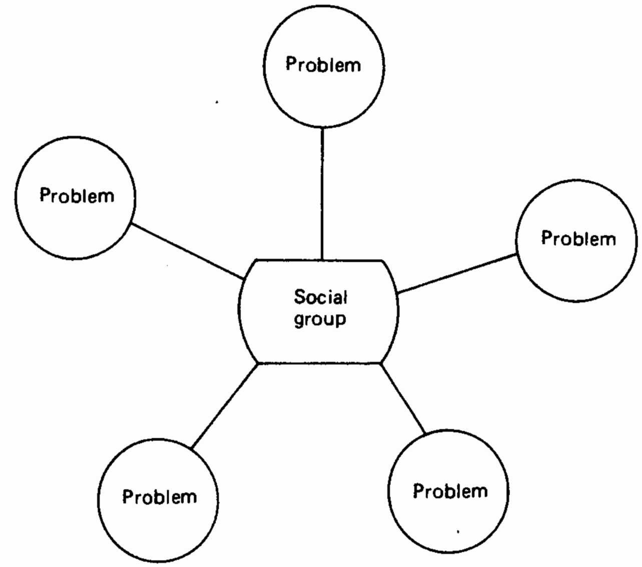

Figure 2.11
Artifacts are described by focusing on the problems perceived by the relevant social groups.

first modern bicycle" (see figure 1.3). All other bicycles were pushed to the margins of history because they are, retrospectively, seen to have failed. If, on the contrary, the various alternatives to the Ordinary are initially[37] put on an equal footing and considered as variants from which the next stable artifact had to be selected (as in figure 1.4), this view could be helpful in avoiding an implicit assumption of linearity.

Second, parts of the descriptive model can effectively be cast in evolutionary terms. A variety of problems are seen by the relevant social groups; some of these problems are selected for further attention; a variety of solutions are then generated; some of these solutions are selected and yield new artifacts. Such an evolutionary representation would thus not exclusively deal with artifacts, but would consist of three layers: variation and selection of (1) problems, (2) solutions, and (3) the resulting artifacts. Thus the results of variation and selection on the level of problems is fed into a further evolutionary process of variation and selection of solutions, which subsequently generate the artifacts (see figure 2.13).

One could try to summarize the narrative of the case study in one enormous drawing, compiling artifacts, relevant social groups, problems,

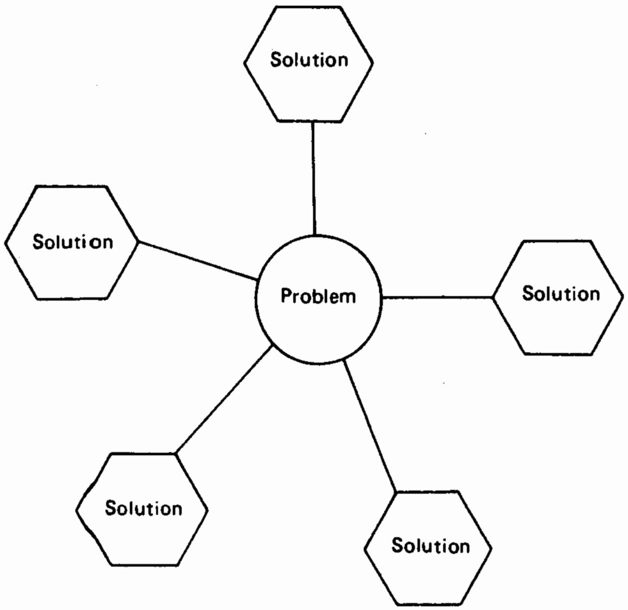

Figure 2.12
Finally, the solutions are described that are seen as available to each of the perceived problems.

solutions, and the subsequently modified artifacts. There are, however, two related problems lurking behind such an evolutionary representation. The first is practical and becomes obvious should the reader accept the challenge and try to make such a drawing of the case study presented in this chapter—it simply cannot be done because of the immense complexity. The other problem is that, if such a multilayered representation of problems/solutions/artifacts is not completely adequate, one almost inevitably ends up with the assumption that an artifact is a constant, fixed entity—to be generated in the variation process and then ushered through the selection processes.[38] In the remainder of this chapter we will find that this is not the case. Rather, an artifact has a fluid and ever-changing character. Each problem and each solution, as soon as they are perceived by a relevant social group, changes the artifact's meaning, whether the solution is implemented or not.

In the next section the history of the bicycle is followed further, with a focus on the solutions that various relevant social groups saw to the safety problem of the Ordinary.

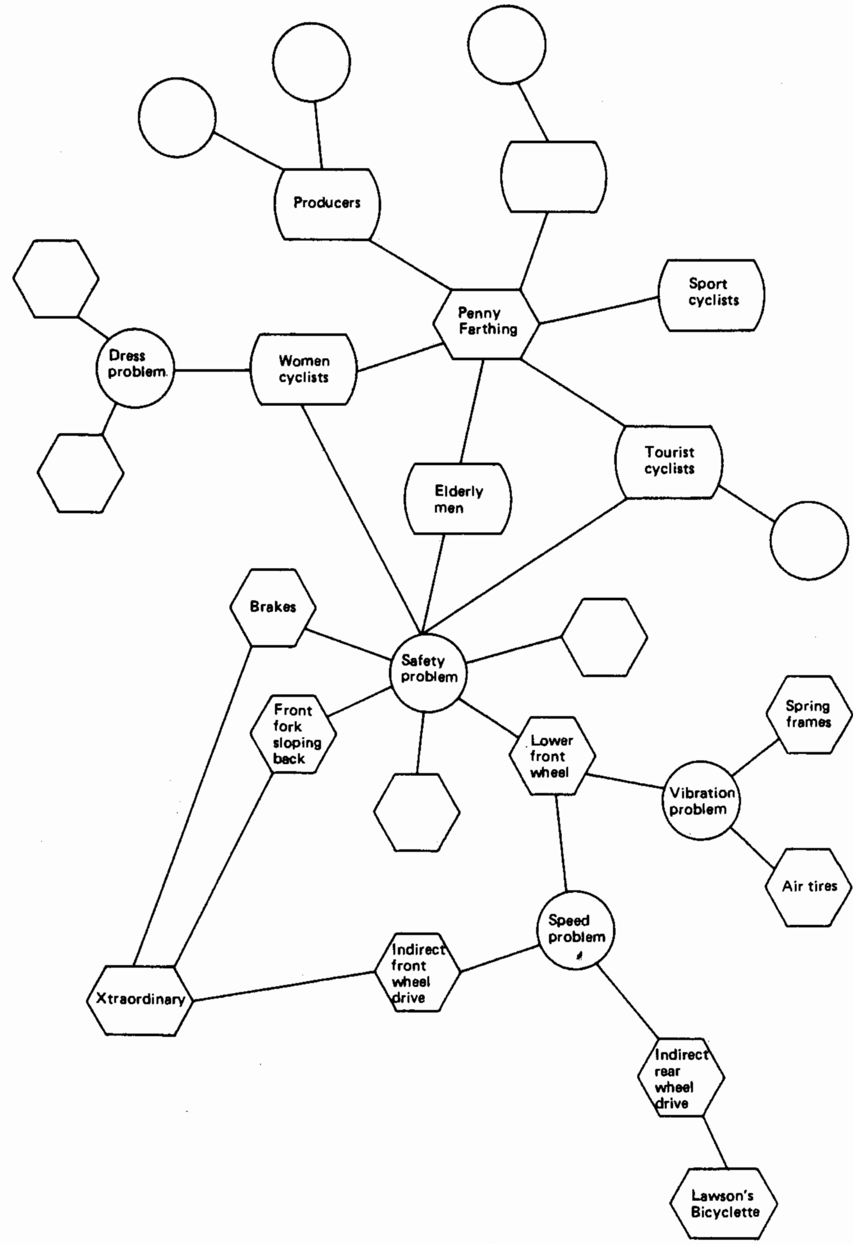

Figure 2.13
Three levels of evolutionary processes may be compiled by superposing figures such as 2.10, 2.11, and 2.12, onto figure 1.4

2.6 Solutions to the Safety Problem of the Ordinary

A great variety of solutions were tried to tackle the safety problem, once it was recognized by manufacturers and inventors. I will discuss them under three rubrics: three-wheeled cycles, modifications of the basic scheme of the Ordinary, and some more radical departures from that basic scheme.

Tricycles

It would be only partly true to describe the tricycle as a solution to the safety problem of the Ordinary, because parallel to the development I have described, from the Draisienne to the bicycle, another genealogy could be drawn of human-driven vehicles with three and four wheels, starting for example with the inventions of Demetrios of Phaleron (308 B.C.) and including the machines of Drais von Sauerbronn (1814).[39] None of these machines, however, reached a stage of commercial viability, and it is unlikely that these designs ever led to more than one prototype. Given the quality of the roads, it is not surprising that these vehicles could not compete with horse-pulled carriages. Moreover, those who could afford such a machine normally would prefer not to propel the "muscle-power cart" themselves—although some of these machines were big enough for servants to ride along and propel, leaving ample space for the owner to enjoy the ride at ease.[40]

A few inventors tried to overcome the disadvantages of the hobby-horse by developing heavy machines with three and four wheels, but none of these went beyond the prototype or toy stage (Woodforde, 1970: 13–15). But in the early 1870s the situation changed. The bicycle had created a market for human-propelled transport vehicles and when the safety problem of the Ordinary had been identified, the tricycle was reinvented as a solution. Moreover, the tricycle promised to solve the problem of staying upright, which many new and less athletic riders found difficult. One of the first successful tricycles was designed by James Starley. The "Coventry Lever Tricycle," patented in 1876, was a two-track machine, originally driven by a lever gear. The lever mechanism was soon changed to a chain drive (Caunter, 1958: 8). This machine became quite popular, especially among lady cyclists. Other designs followed, using all possible schemes to combine the three wheels (see figure 2.14). Propelling the tricycle on the pair of parallel wheels, as for example on the "Coventry Front-Driving Tricycle," caused problems. Because the two wheels were fixed on the axle, the smallest turn caused

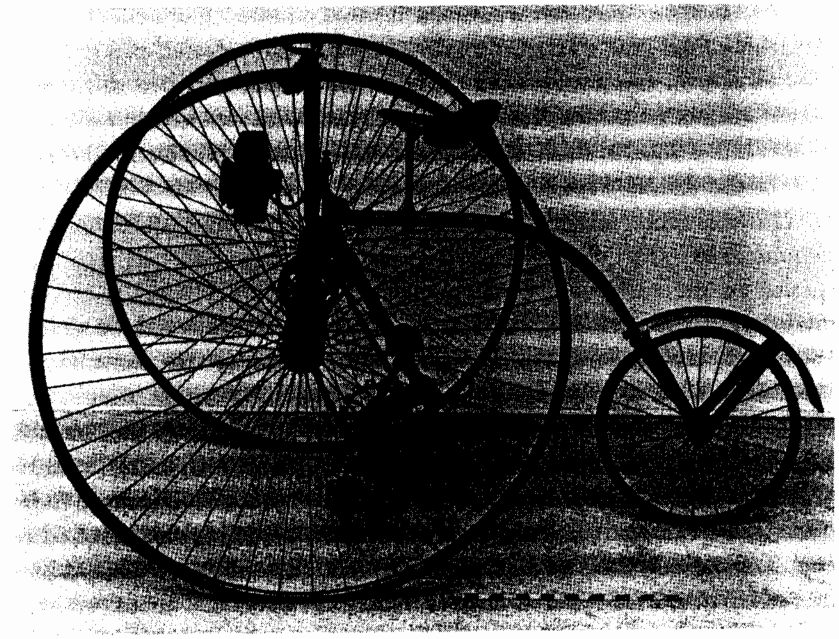

Figure 2.14
The Doubleday and Humber Tricycle was a great success on the racing track, but because of its tendency to swerve on passing over a stone it was not much used as a roadster. The front wheels, also used for steering, are driven by a chain; the right wheel is mounted solidly on the axle, while the left wheel has a nonrigid connection to the axle to allow for different rotation speeds when turning a corner. Photograph courtesy of the Trustees of the Science Museum, London.

tension in the axle, then friction between the two wheels and road, thus making the tricycle swerve. This would happen when meeting a stone, let alone when the machine turned a corner, and the parallel wheels followed circles with different radiuses. The first solution was to let one of the parallel wheels run loose or with a friction coupling on the axle. James Starley developed a solution that is still used in all modern motor vehicles. He is reported to have made such a swerving maneuver one day, when he was cycling with his son William. They were riding a strange contraption called the "Honeymoon Sociable," consisting of two high-wheeled Ordinaries with axels fixed rigidly together to form a four-wheeled two-seater. After their unhappy landing, when sitting in the bed of sticking nettles at the roadside and applying a dock leaf to his hands, Starley got the idea of the differential gear: don't connect the two axles rigidly, but use two bevel wheels in the middle. Immediately after returning home, he started to make a model of this device and the next day he left for the patent office in London.[41] Starley applied this differential gear to a new tricycle, the Salvo Quad, with one steering wheel in front and a fourth small trailing wheel for extra stability in the rear (hence the "quad").

Tricycles were advertised as being adapted to the requirements of women and elderly men. Their novelty gave them—just as had happened to the early velocipedes—a social cachet too. And indeed the aristocracy did go for it, especially after the invention received Queen Victoria's blessing. Williamson (1966) described how this came about. During one of her regular tours on the Isle of Wight in June 1881, Queen Victoria had seen what seemed to be a young woman amid a flashing mass of spinning spokes. Her horse carriage was unable to catch up with this amazing sight, and the Queen could not inspect more closely. Servants were sent out to track down the young woman and to summon her to the royal residency at Osborne House. The girl was found to be Miss Roach, daughter of the local Starley agent who encouraged his daughter, for promotional reasons, to ride the new Salvo Quad as much as possible. She came to Osborne House and demonstrated the tricycle to the Queen, who "must have been gratified to see that her performance was really very graceful and one which by no stretch of the imagination could be termed 'unladylike'" (Williamson, 1966: 76). Queen Victoria was interested enough to order two tricycles immediately, and a royal command was added that the inventor should be present on delivery. Thus, a few weeks later, James Starley, very nervous and with a brand new silk hat, traveled to Osborne House where the Salvo Quads were delivered through the local agent. The Queen was sitting on the lawn on a small garden chair, reading papers with a secretary; Prince Leopold, then about twenty-seven years old, was examining one Salvo Quad the stood under a tree. Starley was presented to the Queen, who said some pleasant words to him and gave him a leather case containing a silver watch as a memento of his visit. Then, Starley wrote in a letter to his wife,

> I was quite overcome and bowed so low that I nearly toppled over as I said I am very honoured, Ma'am. Then the gentleman led me away and I was surprised and pleased when the Prince came along and asked me to explain the working of the tricycle to him. A servant was wheeling it behind. We found a nice level drive where I got on and was soon rolling along in fine style. He seemed very pleased with it and thanked me very kindly.[42]

The Salvo Quad was immediately renamed into Royal Salvo, and within a few years the tricycle had become fashionable among the elite. Lord Albemarle wrote that there was not a crowned head who had not a fleet of tricycles, both within and outside Europe:

> I have seen a picture in which the Maharajah of an Indian state, together with the British resident at his court and all the great officers of the durbah, are seated on tricycles at the gate of the palace, and gaze at the lens of the camera with the breathless attention usual on such occasions.[43]

It was no surprise then that the Tricyclists' Association sought special privileges in the London parks because tricyclists were supposed to be better bred than bicyclists.[44] And in 1882 a Tricycle Union was founded, because many tricyclists wanted to distance themselves from the bicyclists, "who are a disgrace to the pastime, while Tricycling includes Princes, Princesses, Dukes, Earls, etc." (Ritchie, 1975: 113).

It is difficult to appreciate the importance of the tricycle in hindsight, as most of us associate the tricycle with children. However, the tricycle was a very viable alternative to the bicycle in the 1880s and 1890s and not some "historical mistake," as it may seem now. Most cycle manufacturers produced bicycles as well as tricycles.[45] For example, Messrs. Singer & Co manufactured a tricycle in 1888 that embodied the same state-of-the-art technology employed in their 1890 bicycles. A 1886 catalogue of all British cycles described 89 different bicycles and 106 tricycles.[46] Thus, notwithstanding the initial efforts to restrict the use of tricycles to the upper class, the tricycle gained widespread acceptance. In 1883, the "Bicycle Touring Club," founded in 1878, changed its name to the "Cyclists Touring Club." Many people were convinced that it would just be a matter of time before the tricycle was the only commercially available cycle (Rauck et al., 1979: 60). Especially as a vehicle for business purposes, it seemed to have a splendid future. The *Evening Standard* was distributed by means of the Singer tricycle called "Carrier," and the Post Office employed scarlet tricycles for delivering parcels. A specific illustration of the impact the tricycle had on designers of the time features the Otto Dicycle (see figure 2.15). This was a bicycle in the sense that it had but two wheels, but they were arranged in a "tricycle way": the dicycle had two large parallel wheels, and the rider was seated in between. The machine enjoyed some popularity; the Birmingham Small Arms Co. built 1,000 machines of this design. The "Ottoists" claimed that their dicycle was especially effective when riding against the wind,

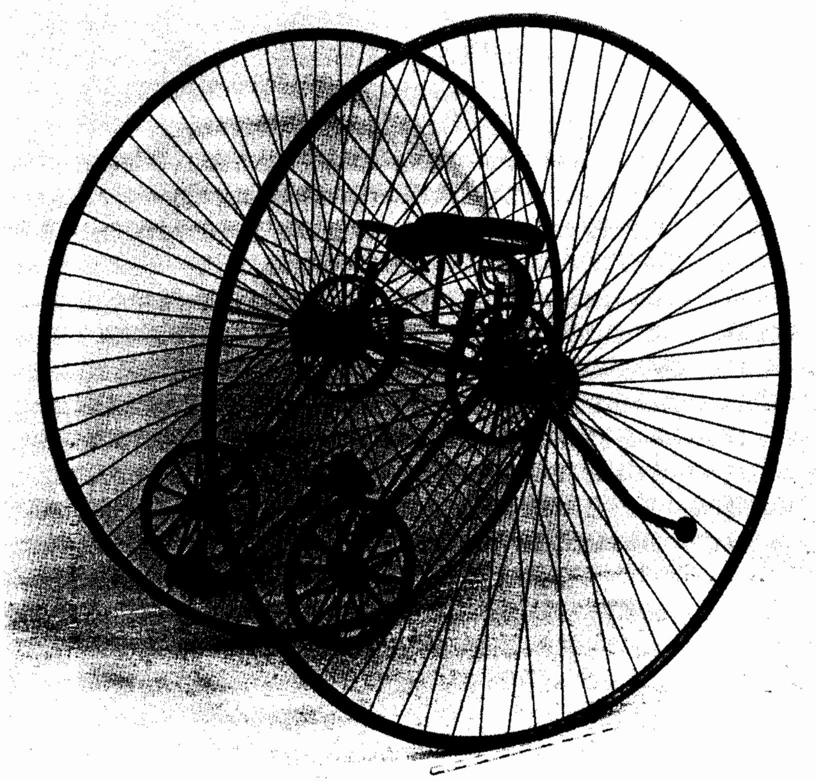

Figure 2.15
The Otto Dicycle was patented between 1879 and 1881 by E.C.F. Otto. From the back of the frame, supported by the axle, projects a small rubber-tired roller, which prevents the frame and rider from swinging too far backward. This roller can be used as emergency brake by leaning back; normally it will be well off the ground. The wheels turn loose on the axle and are driven by two rubber-sheathed pulleys. Handles on each side of the rider allowed the pulleys to be slackened selectively, so that one wheel could turn faster than the other and the machine could make a turn. Although keeping one's balance was said to be rather easy, steering downhill took longer to master. Photograph courtesy of the Trustees of the Science Museum, London.

because by leaning forward the riders could get out over the pedals, thus bringing all their weight to bear directly on them.

As mentioned, the tricycle played an important role in providing an opportunity for women to cycle. The acceptability of women riding tricycles was linked to the association of tricycling with the upper classes: "Tricyclists will generally be of a better class than bicyclists, and will seldom consist of mere beardless youths, but men of position and experience, and above all, by the fair sex."[47] Tricycling made it possible for young ladies of good breeding to get out of their stuffy Victorian homes. The tricycle (as some time later the bicycle) was not so much used by women to go somewhere, but rather to get away. And thus it showed the way to a loosening of customs, for example in the domain of dress. The Cyclists Touring Club seriously discussed the dress that should be worn by lady tricyclists (Woodforde, 1970: 123). The crucial element was assuring propriety by wearing knickerbockers or trousers beneath a full-length skirt. Still, this English "C.T.C. uniform" was a long way from the American "Bloomers," which will be discussed later. "One reason for the protection which ladies undoubtedly find in the C.T.C. uniform lies in the fact that it is so little remarkable, and so closely resembles that ordinarily worn by the wife of the parson or doctor."[48] Tricycling, too, was an activity during which a woman should not display herself too freely. But even so, tricycling engaged women in cycling and thus paved the way for women's participation in bicycling. Because the tricycle was appreciated for solving the safety problem of the high-wheeled Ordinary and thereby allowing women and elderly men to engage in cycling, it made bicycle producers acutely aware of these groups as potential markets for bicycle sales. This was further stimulated by recognizing that the tricycle was not without problems itself.

Surely it was more easy to keep one's balance on a tricycle than on a bicycle, and making a "header" was less likely too. But the tricycle appeared to have safety problems of its own. Most tricycles had three tracks, where the bicycle had only one when riding straight on. This made the tricycle more subject to the perils of the roads, for it was more difficult to avoid stones and holes. On the roads of the 1890s, this was a considerable drawback. Another circumstance that caused tricycles to be involved in accidents was that most of them did not have effective brakes. The rider had to "reverse the action of his machine" by trying to back-pedal. And this could be difficult. Especially when going downhill, it was crucial not to let your feet slip off the pedals. When trying to regain control over those more and more quickly revolving pedals, many tricyclists were lifted from their seats. As a passing cyclist commented when helping a tricyclist after such a downhill accident, "You lost control. Should never do that, you know. Might have ruined your machine."[49]

Further, sitting between the two large wheels, as required by most tricycle configurations, was a safe and stable position as long as you were rolling along smoothly, but it became a very hazardous place to be when taking a spill. In such a case, it was almost impossible not to get entangled in the spokes of the large wheels. In 1883, tricycle accidents seem to have outnumbered accidents with bicycles, and the *Times* of that year reported a death caused by a fall from a tricycle (Woodforde, 1970: 67).

Thus the tricycle offered a partial solution to the safety problems of the Ordinary, and therefore it was a substantial commercial success. By the 1920s new tricycles were still used and sold, although few large cycle manufacturers were producing them. Instead, local assemblers were the typical producers of these custom-designed machines (Grew, 1921: 22). But since these machines posed some new problems of their own, the success was not complete and there was room for alternative solutions to the Ordinary's safety problem.

Safety Ordinaries

Another class of attempts to solve the high-wheeler's safety problem was based on modifying the basic scheme of the Ordinary bicycle. Moving the saddle backward was an obvious way to reduce the problem; without further modifications, however, this would bring the rider's weight above the small rear wheel and thus make its vibration more manifest. The only way to cope with this vibration problem was to enlarge the rear wheel. An additional advantage was that once the rear wheel was of significant size, the rider was positioned between the two wheels, rather than above one; this would also reduce vibration.[50] But this alteration made the bicycle heavier and thus more difficult to handle. Moreover, such an enlarged rear wheel was out of syne with the aesthetic norms of the community of high-wheel bicyclists, where the smallness of the rear wheel emphasized the loftiness of the rider. However, because the goal of making the Ordinary safer was already out of sync with the high-wheelers' norms, bicycle designers were probably prepared to put up with this drawback, expecting the relatively bigger rear wheel to be acceptable to potential buyers of these new machines. This new class of bicycles was soon to be called safety Ordinaries.

Another disadvantage of moving the saddle backward was that treading the pedals became less comfortable: because he was now behind the

pedals rather than almost directly above them, the bicyclist, as in the case of the velocipede, would push himself backward with his legs, and counteract that force by pulling forward on the handlebar. One way to tackle this problem was to replace the pedals with some lever mechanism extending backward. John Beale had already patented such a mechanism in 1869, but its application in a commercial bicycle had to wait until about 1874, when the Facile bicycle was produced by Ellis & Co in London. The front wheel was reduced in size to 44 inches, the saddle was placed farther back, and the pedals were lowered by placing them on the rear ends of levers mounted below the axle. These levers were pivoted to forward extensions of the fork and their midpoints were connected to the cranks with short links (Caunter, 1958: 8).

On the Facile, the rider's feet made an up-and-down movement, rather than a rotary action. This was claimed to be very effective, especially when climbing a hill (see figure 2.16). The question of which of the two types of motion was best for cycling was hotly debated at the time. As was so often the case in bicycle history, enthusiasts tried to settle this issue by testing the bicycles in races and record-breaking efforts. Significantly, the Facile was not used for high-speed racing and sprinting, but primarily for hill climbing and long-distance riding (Griffin, 1886: 32). The rotary motion was generally preferred for sprinting (Ritchie, 1975: 126).

In 1878, G. Singer patented a device similar to the Facile (Singer, 1878). In this design, named the Xtraordinary, the backward position of the saddle was realized by tilting the front fork backward (see figure 2.17). However, such a sloping front fork, without further modification, would have made steering quite difficult: the center of the wheel—and thus the point of action of the bicycle's weight—was forward of the point at which the wheel had contact with the ground, and so the wheel tended to veer sharply and needed to be kept straight by continuous application of force. This problem was solved by the idea (also included in this patent) of giving the front fork such a form that the center line of the steering head met the ground at the point of contact between wheel and ground. The pedals of the Xtraordinary were brought backward by mounting them on levers that moved the crank pins. The upper end of each lever, attached by a link to a point near the top of the front fork, moved in an elliptical arc while the pedals made their "normal" rotary movement (Caunter, 1958: 9).

Although in the case of the Xtraordinary, the rotational speed of pedal and crank was still the same, one could choose different force-movement

Figure 2.16
The "Facile" was advertised by referring to the records set in long-distance racing. The riders performing these feats were often paid by the manufacturing firm: the first "professional" bicyclists. (From an advertisement in *The Cyclist*, June 4, 1884: 585; reprinted from Ritchie (1975).)

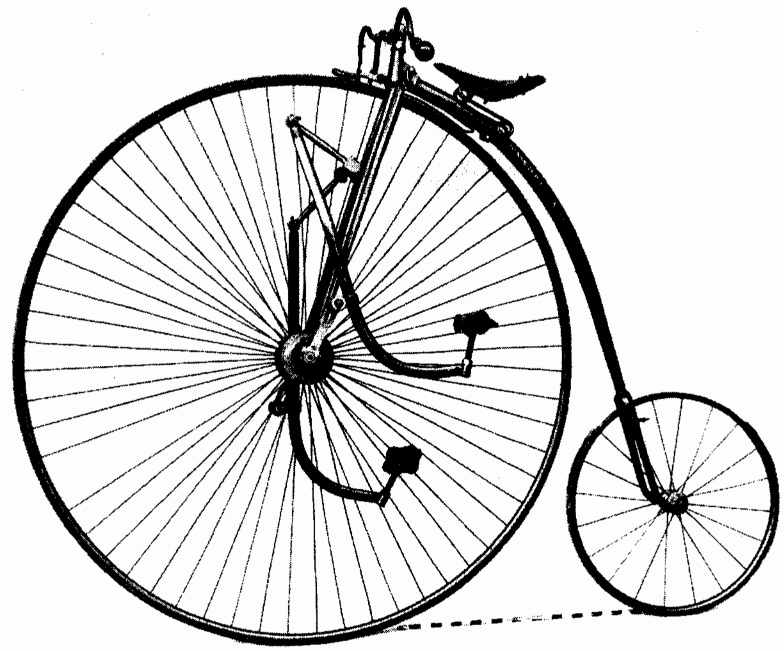

Figure 2.17
The "Xtraordinary," or "Xtra" for short, was produced by Messrs. Singer & Co., Coventry, in 1878. The levers allow the rider a downward push, although the saddle is moved backward. Photograph courtesy of the Trustees of the Science Museum, London.

ratios by varying the length of the levers and the position of the linking point of the crank pins. In principal this was no different from choosing specific lengths of cranks as possible in earlier models, but here the lever mechanism was mode more flexible (Griffin, 1886: 11). The levers of the Facile and the Xtraordinary perhaps point to the designers' growing awareness of the gearing possibilities of using "intermediate" driving mechanisms. In any case, several designs were tried to solve the Ordinary's safety problem, primarily by lowering the front wheel, and as an intrinsic part of that modification, to incorporate an accelerating mechanism to compensate for the resulting lower top speed.

Complicated combinations of levers and gears were employed in the Sun and Planet, the Devon Safety, the Dutton Safety, and the Raccoon Safety.[51] These machines still had the upright front fork and the forward-positioned saddle of the Ordinary, but their front wheels were significantly lower. None of these became a commercial success.

In Marseille, Rousseau was the first to add a chain drive to an Ordinary. He designed a bicycle called Sûr in 1877 that had a front wheel with a radius two-thirds that of an Ordinary. The wheel was driven by a gears-and-chain mechanism with a gear ratio of 2:3, exactly compensating for the smaller wheel radius. The Sûr, however, was not successful either, although a very similar design by E. C. F. Otto and J. Wallis did become a commercial success in Britain. Their Kangaroo had a front wheel of 36 inches, which was geared up to 54 inches (see figure 2.18). One problem with their mechanism was the arrangement with two independent chains: each pedal had to be raised by the "slack" side of its chain, which caused, unless it was kept carefully tightened, two shocks per revolution, jarring the gear (Caunter, 1958: 9–10). The Kangaroo

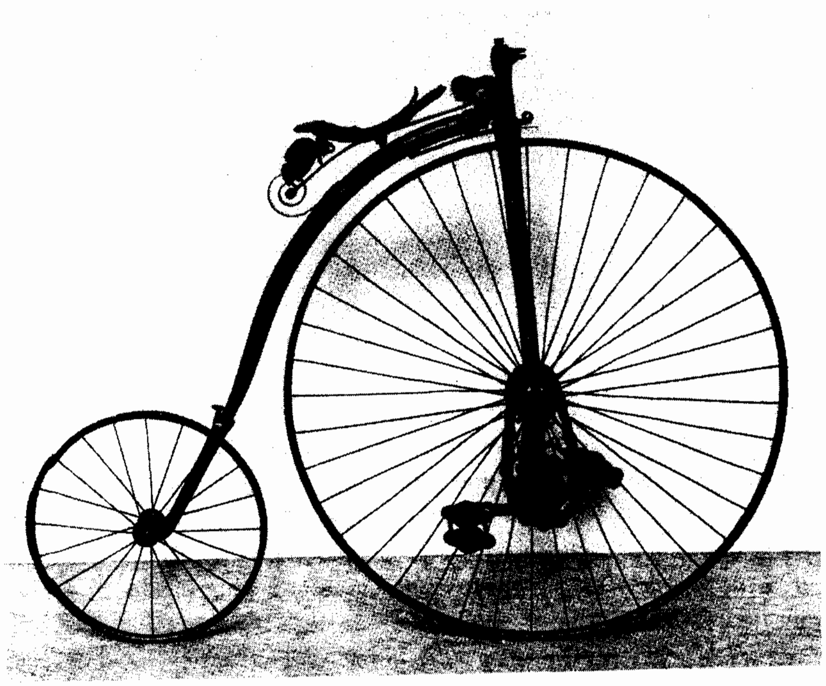

Figure 2.18
The "Kangeroo" safety Ordinary, patented in 1878 by E.C.F. Otto and J. Wallis, was built by several well-known manufacturers. Photograph courtesy of the Trustees of the Science Museum, London.

was manufactured by the firm of Hillman, Herbert, and Cooper. They publicly launched the Kangaroo in 1885 by organizing a race, which the professional cyclist G. Smith won on a Kangaroo. The average speed he obtained (14 miles per hour; 22.4 kilometers per hour) was more than twice the speed Hillman and Starley had achieved in their historic ride from London to Coventry. The Kangaroo scheme was taken up by several designers, and in the 1886 catalogue of bicycles some ten different makes of chain-driven Ordinaries were described (Griffin, 1886).

These safeties were claimed to be safer than the Ordinaries: the Facile, for example, was hailed by its makers as "Easy to learn. Easy to ride. Easy to mount. Easy to dismount. Safe from side-falls. Safe from headers."[52] And not only the manufacturers were enthusiastic. New bicycles were routinely tested and reviewed in the various journals, and most of these new machines were well received. For example, the Kangaroo was said to be

> a thoroughly sound and reliable little mount, likely to win its way more and more into popular favour, particularly among those who value their necks too highly to risk them upon the ordinary bicycle, or who are occasionally apt to characterize the propulsion of a heavy three-wheeler—as Dickens' friend did the turning of the mangle—as "a demm'd horrid grind."[53]

But from the advice given by *Cycling* in 1887 about coasting on a Kangaroo, the conclusion can be drawn that there was still considerable chance of being sent flying over the handlebar. A Kangaroo rider was cautioned to "throw his body as far back as possible" and to apply the brake very gradually. Thus the greater safety of the safety Ordinaries seems to boil down to falling less hard rather than less often.

One rather colorful solution left the height of the Ordinary unmodified, and only sought to enable its rider to land on his feet in case of a header. Franz Schröder constructed a safety handlebar, or "Non-Header" or "Non-Cropper" as he proposed to call it. When colliding head-on with some obstacle, the rider would be projected forward along with the handlebar, which disconnected automatically from the front fork (Rauck et al., 1979: 51). Schröder arranged a demonstration for the director and chief engineer of the bicycle manufacturing firm Frankenburger & Ottenstein in Neurenberg. When Schröder ran into the large stone that he had brought to the demonstration, he landed squarely in front of the Ordinary, on his feet. The director was wildly enthusiastic but the engineer less so, wondering what would happen to a somewhat less athletic rider. They summoned a worker to test the device, and he indeed landed on his bottom. This was nonetheless considered an improvement over landing on his head, and the "Non-Header" entered into production. The invention, however, did not fundamentally change the course of events by solving the Ordinary's safety problem in the eyes of all. A bitter patent fight evolved between Schröder and a Czech named Havlik who had simultaneously patented a similar device. In addition to challenging the fact that Schröder's invention had predated his own, Havlik also disputed its effectiveness, claiming that it would castrate its rider because a part of the steering tube was left on top of the front fork. Moreover, consumers were sending angry letters to Frankenburger & Ottenstein, complaining that the handlebar disconnected after only a minor push during regular cycling; frantically trying to keep control of the bicycle by holding on to the front fork, hapless riders inevitably landed on the ground entangled in their Ordinary (Timm, 1984: 194–202).

Reordering the Basic Scheme

All bicycles inspired by the safety problem of the high-wheeler were developed in roughly the same period and to some extent in parallel. Ordinaries, tricycles, safety Ordinaries, and the machines to be discussed in this section were all striving for the cyclists' favor. Considering the uneven quality of the historical material and the inevitable overlap of the various designs, it is hazardous to lend much weight to the chronological order as distilled from available sources. For example, the bicycles described in this section cannot be considered to form a logical follow-up to the safety Ordinaries of the previous section. Moreover, they do not bear much relation to one another. These designs deserve a separate discussion, because they differed more radically from the basic scheme of the Ordinary than the machines previously described.

One radical solution to the Ordinary's safety problem was to reverse the order of the big and small wheels. One bicycle that can be viewed as the outgrowth of this idea was patented by Henry J. Lawson and J. Likeman in 1878. Others, discussed below, were primarily of American origin. The Lawson and Likeman bicycle bore a close resemblance to MacMillan's machine. But when its frame is closely analyzed, the Lawson and Likeman bicycle clearly reveals its origin as an Ordinary. However, it is driven backward. To bring the rider within reach of the handlebar, which was of the normal Ordinary construction but now mounted on the small wheel, the saddle had to be moved to a position between the wheels. This low positioning of the saddle enabled the cyclist

to reach the ground with his feet while staying on the bicycle (Caunter, 1958: 8). Indeed, this machine could have been called a "safety."[54] However, it seems not to have been much of a commercial success.

Another family of bicycles, designed according to the same basic idea, did meet with success. Viewed from a distance, the obvious difference with the previous design was the position of the rider, who sat much more on top of the large wheel, which had consequences for the steering mechanism. Several patents were taken out on designs according to this scheme.[55] The available sources are ambiguous about the construction date of the first successful bicycle of this principle. One of the first of these machines was probably produced by the H. B. Smith Machine Company of Smithville, New Jersey, and publicly exhibited at the meeting of the League of American Wheelmen in Boston, on November 23, 1981.[56]

The Star bicycle, as the Smith machine was called, had its saddle forward of the big rear wheel and thus needed a lever-type of driving mechanism to bring the pedals forward to the position of the rider's feet (see figure 2.19). Two drums were attached to the ends of the rear axle.

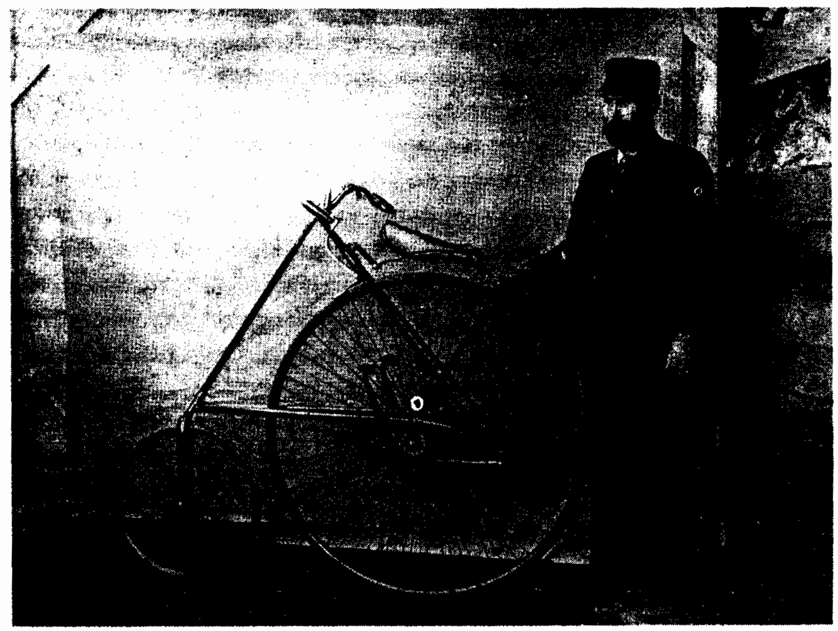

Figure 2.19
The American "Star" bicycle, first manufactured around 1881. Photograph courtesy of the Trustees of the Science Museum, London.

A leather strap was wound around each drum several times, one end of the strap being attached to the drum and the other end to the lever on that side. As a lever was pushed down, its strap was pulled, which made the drum turn. The drum was attached to the axle by a ratchet mechanism and thus forced the wheel to turn as well. At the end of a stroke, the foot pressure was released and a spring within the drum wound the strap back, bringing the lever to its original position. The effective attachment point of the straps on the levers could be adjusted, thus providing a kind of "gear shift," as two different driving ratios were possible.[57] Normally the levers would be pushed down alternatingly, but because they worked independently of each other, they could be pressed down together in one big stroke. This was considered an advantage for racing purposes, to obtain a quick start or produce a spurt (Caunter, 1958: 14).

Although the small front wheel of the Star suggests difficulty in steering as well as in coping with rough ground, this seems to have been compensated for by its safety and the advantages of the driving mechanism.[58] The Star had considerable success in the United States. But although it was sold in Europe, it did not acquire a significant share of the market in Britain or on the continent.[59] Perhaps the Star was evaluated in comparison with the safety Ordinaries and not found a very credible competitor. In turn, the British safety Ordinaries did not obtain a foothold in the United States.

Another way of reordering the basic scheme of the Ordinary was to move the drive to the rear wheel. In 1879, H. J. Lawson, by that point manager of the Tangent and Coventry Tricycle Company, took out a patent on a design of a bicycle that had a chain drive on the rear wheel (see figure 2.20).[60] The diameters of the wheels revealed its origin: the Ordinary. Now the only function of the relatively large front wheel was to offer a comfortable ride, but the comfort was reduced by the still quite small rear wheel. Because the saddle was mounted on a spring, the result may have been acceptable, though. The front wheel was 40 inches and the rear wheel 24 inches, but geared up to 40 inches as well (Caunter, 1958: 10–11). Lawson called his machine a "Bicyclette."

Whereas the latest types of Ordinary were considered slim and graceful, the aesthetic aspect of the Bicyclette was not much appreciated. Both the public and the trade just could not swallow the grotesque form of the Bicyclette, which was compared to a crocodile because of its elongated frame.[61] A small number of Bicyclettes were manufactured, but they proved to be a commercial failure even though they were rather exten-

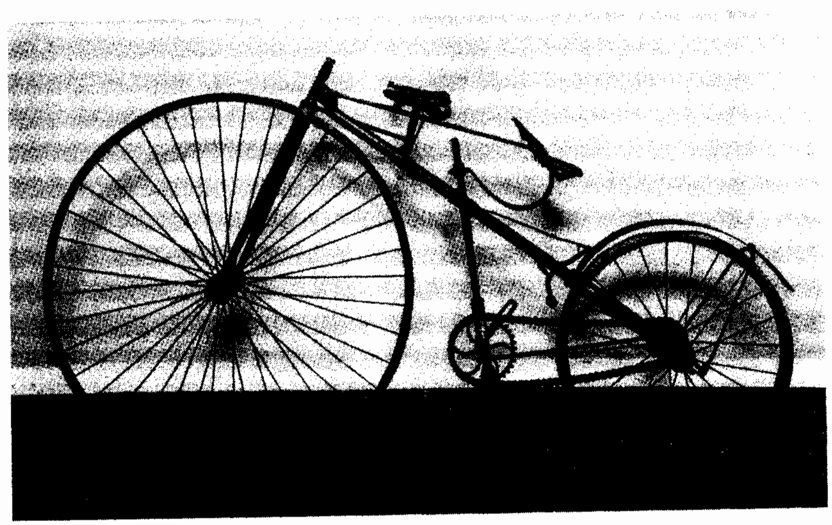

Figure 2.20
Lawson's "Bicyclette," patented in 1879. Photograph courtesy of the Trustees of the Science Museum, London.

sively advertised and exhibited. In many bicycle histories the Bicyclette is said to be "ahead of its time."

Although Lawson's Bicyclette was not successful, in the early 1880s there was enough awareness of the safety problem of the Ordinary to stimulate further attempts along these lines. A real boom of different bicycle designs occurred between 1884 and 1888: besides new Ordinaries, safety Ordinaries, and tricycles, lower-wheeled bicycles proliferated. Frequently the words "dwarf" and "safety" were combined in their names. John Kemp Starley, a nephew of James Starley, had started a partnership with William Sutton. After manufacturing Ordinaries and tricycles for some years, they presented in 1884 a new design, comprising a 36 inches front wheel, coupling-rod steering, a chain drive to the rear wheel, and a frame that seemed, when viewed from a distance, to have a diamond shape (see figure 2.21). This machine, named the Rover, is a curious mixture of elements found in the other bicycles described in this section. The relative size of the wheels, the chain drive, and the steering mechanism are very similar to Lawson's Bicyclette, while the main tube of the frame is formed like that of the Star (and the Ordinary). New is the extra support of the saddle by a fork on the rear wheel. This extra support would soon develop into a true part of the

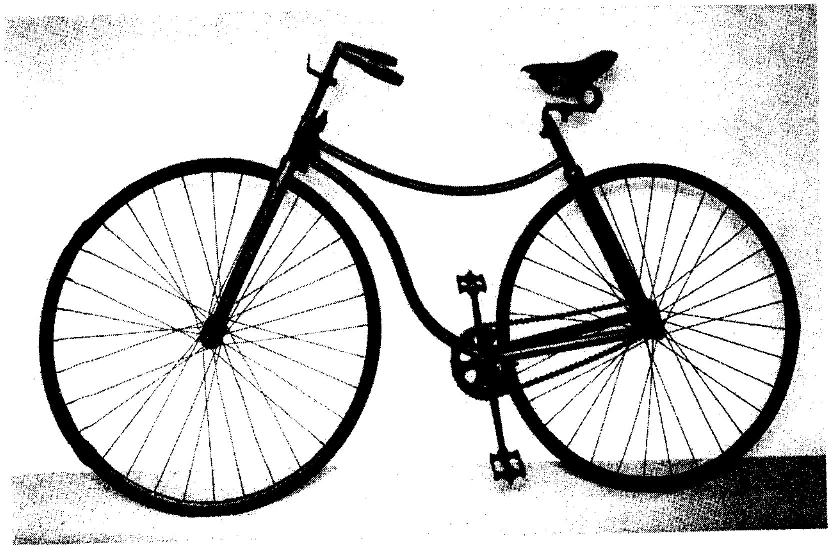

Figure 2.21
"The Rover," designed by J. K. Starley and W. Sutton in 1884, was the first dwarf safety with a diamondlike frame. Photograph courtesy of the Trustees of the Science Museum, London.

frame, thus resulting in the diamond-shaped frame that most (male) bicycles would have up to today. Effectively, however, the Rover still had a single backbone frame.

The Rover was presented to the public during the Stanley Exhibition, a large annual event held in London. All important cycle manufacturers sent their latest models for display, and all members of the trade came to keep abreast of recent developments and to place orders for the coming year. Starley and Sutton's new Rover must have seemed a pygmy among all the lofty Ordinaries. Some traders approved its small wheels and assumed it to be suited for nervous or less athletic cyclists. Others were inclined to scoff and nicknamed it "Beetle" or "Crawler" (Williamson, 1966: 103). Starley and Sutton started to organize races in which they had professional racers riding their Rover. For the first race Starley and Sutton used the same route Hillman had used for the launching race of the Kangaroo in 1885. They could be satisfied by this promotional move: the record set on a Kangaroo was beaten by the same George Smith, but this time on a Rover.[62] As the sales started to increase, Starley continued to revise his Rover, turning out a second and third model with only a few months in between. I will return to these revisions shortly.

Figure 2.22
From 1884 to 1886 several new designs were developed, in various aspects widely different from the basic scheme of the Ordinary bicycle. The Humber "Dwarf Safety Roadster," also designed in 1884, had a trapezial frame. In their model of 1886, Humber introduced a front fork with the forward bending of the Singer 1878 bicycle. Photograph courtesy of the Trustees of the Science Museum, London.

The new designs from the mid-1880s clearly show that all elements of the basic scheme of the Ordinary had been called into question (see figure 2.22). The Birmingham Small Arms Company, for example, made a bicycle of which the cross frame was radically different from all previous frames based on the single backbone of the Ordinary. This bicycle had a large chain-driven rear wheel and a small indirectly steered front wheel. The new frame consisted of an almost straight tube between the axle of the traveling wheel and the bracket for the steering front fork, and a second rod, perpendicular to the first, which supported the saddle, the indirect steering mechanism with handlebar, and the crank bracket with sprocket wheel. This invention had for its object "to give greater rigidity to the framing of the bicycle so that the seat and steering mechanism may be free from the unsteadiness of those parts in bicycles of the ordinary kind."[63]

Lawson played an indirect role in stimulating the design of this bicycle. He had approached B.S.A. with a proposal to manufacture his new design for a lady's safety bicycle. This machine had a large chain-driven rear wheel, a smaller front wheel, and a single-tube frame that bent upward and forward to support the saddle (Lawson, 1884). B.S.A. declined the offer but agreed to make two prototypes for Lawson. While doing that, they decided to design their own safety bicycle and assembled this machine as much as possible from their standard tricycle parts (Caunter, 1955: 35).

Another design that departed from the old frame scheme was patented by the gun maker H. Wallis in 1884 and produced by Messrs. Humber & Co (Wallis, 1884). Its frame had a trapezial form, which proved stiffer and more compact than the single backbone frame of the Ordinary bicycle. Another important feature, in comparison with competing 1884 designs, was its direct steering. The small front wheel proved to be problematic on rough roads, however.

J. McCammon patented a dwarf bicycle suitable for ladies. The single backbone of the frame dropped deep between the wheels, so as to allow women to mount the machine more easily (Caunter, 1958: 14). This McCammon bicycle had the same steering wheel scheme as the Humber, but also featured the slightly backward bending of the front fork that was used in the B.S.A. machine.

Starley and Sutton further revised their Rover by making the steering direct, giving the front fork much rake and changing the frame from the original single backbone to the beginning of a diamondlike shape. The front fork is straight, so it is not surprising that "at first the steering feels rather difficult, as the pilot wheel has no automatic assistance or fly-back spring to keep it straight" (Griffin, 1886: 44). It is unclear why they did not use Singer's idea, described previously, of bending the front fork to counter this effect. Nevertheless, consumer tester Griffin concluded his report on this Rover on a positive note, predicting a successful future for it.

In spite of the emergence of quite a number of dwarf safeties, many people still were convinced that the high-wheeled Ordinary bicycle would never be superseded by those geared-up small-wheelers. In a report on the yearly Stanley Exhibition of Cycles, it was observed that

> No radical changes have been made in the construction of cycles during the past year, and the tendency is to settle down to three types of machines—the ordinary bicycle, the rear-driven safety bicycle, and the direct front-steering tricycle, whether single or tandem. (Engineer, 1888a: 118)

Besides mud splashing on the rider's feet[64] and the power wasted by the chain drive, the most prominent problem was the vibration of the low-wheeler (Woodforde, 1970: 87).

At the 1888 exhibition most safeties were equipped with some sort of antivibration gear. Many frames were constructed with several hinges instead of rigid connections. Springs were mounted between the wheel axles and the frame, between handlebar and front fork, between saddle and frame, and between crank bracket and frame (Engineer, 1888a: 118). The awareness of the vibration problem seems to have increased in subsequent years. In the 1889 cycle show it was clear that

> With the introduction of the rear-driving safety bicycle has arisen a demand for antivibration devices, as the small wheels of these machines are conducive to considerable vibration, even on the best of roads. Nearly every exhibitor of this type of machine has some appliance to suppress vibration. (Engineer, 1889: 158)

In the report on the 1890 show, the situation is even more pronounced (Engineer, 1890b: 138). One of the spring frames that was most successful at the 1890 cycle show had been patented in 1885 by O. Macarthy. The machine was manufactured by Messrs. C. A. Linley and J. Biggs (see figure 2.23). The sloping backbone that joined the rear axle with the steering head and front fork was connected to the rest of the bicycle by springs and hinges. Thus all bicycle parts with which the rider had contact (the saddle, the handlebar, the cranks) had an elastic connection to the rest of the machine (Caunter, 1958: 14–15 and Caunter, 1955: 35–36). However, not many of the antivibration devices were strong and durable: "Of those exhibited for the first time too many are conspicuous by their complication; we should imagine that their designers were in many cases ignorant of the first principles of mechanics" (Engineer, 1889: 158). And of course, even the successful "Whippet" with its many movable parts needed more attention than an ordinary bicycle.

It is not surprising then that the safety bicycle was not more than one of the three alternative types of cycle, without threatening the market share of the other two, the Ordinary bicycle and the tricycle. This changed when the air tire was made available for bicycles.

2.7 *Interpretative Flexibility*

The bicycle story will be interrupted again to discuss another issue related to the descriptive model I am developing. In the previous sections I have described the various artifacts through the eyes of relevant

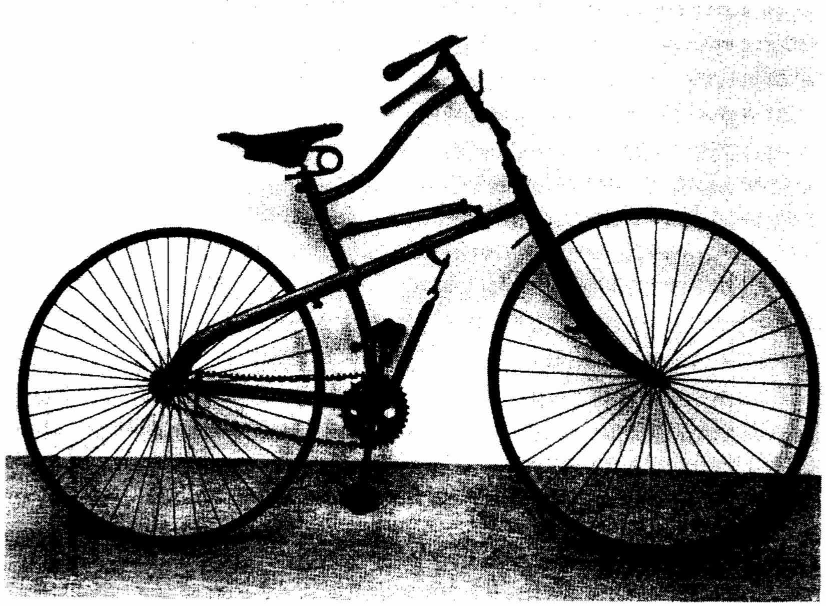

Figure 2.23
The "Whippet" safety bicycle was patented and built in 1885. The relative positions of saddle, handlebar, and cranks were fixed, since these three formed a rigid triangle that was isolated from the main backbone of the frame by a strong coil spring, a movable shackle in the steering rod, and a hinged tube between backbone and steering pillar. Photograph courtesy of the Trustees of the Science Museum, London.

social groups. Where the differences between the various social groups were taken seriously, quite different descriptions did result. Until this point, however, this was left rather implicit. I shall now discuss more explicitly the consequences of those differences in the meanings attributed to an artifact by various relevant social groups.

For example, for the social group of Ordinary nonusers an important aspect of the high-wheeled Ordinary was that it could easily topple over, resulting in a hard fall; the machine was difficult to mount, risky to ride, and not easy to dismount. It was, in short, an *Unsafe Bicycle*. For another relevant social group, the users of the Ordinary, the machine was also seen as risky, but rather than being considered a problem, this was one of its attractive features. Young and often upper-class men could display their athletic skills and daring by showing off in the London parks. To impress the riders' lady friends, the risky nature of the Ordinary was

essential. Thus the meanings attributed to the machine by the group of Ordinary users made it a *Macho Bicycle*. This Macho Bicycle was, I will argue, radically different from the Unsafe Bicycle—it was designed to meet different criteria; it was sold, bought, and used for different purposes; it was evaluated to different standards, it was considered a machine that worked whereas the Unsafe Bicycle was a *nonworking machine*.[65]

Deconstructing the Ordinary bicycle into two different artifacts allows us to explain its "working" or "nonworking." There is no universal time- and culture-independent criterion with which to judge whether the high-wheeled bicycle was working or not. Is the Ordinary a nonworking machine because it was highly dangerous and very difficult to master? Or was it a well-working device because it displayed so nicely the athletic skills of the young upper class and because it dealt so effectively with bumps and mud puddles in the road? Only by reversing the question—that is, by asking under what conditions the high-wheeled Ordinary constituted a well-working machine and under what other conditions it was utterly nonworking—can we hope to begin to understand technical development.

In terms of the descriptive model, this implies the following. The artifact Ordinary is deconstructed into two different artifacts. Each of these artifacts, the "Unsafe," and the "Macho" are described as constituted by a relevant social group, and this description also includes a specification of what counts as "working" for that machine, for that group. In this way, the "working" and "nonworking" are now being treated as *explanandum*, rather than used as *explanans* for the development of technical artifacts. The "working" and "nonworking" of an artifact are socially constructed assessments, rather than intrinsic properties of the artifact. One artifact (in the old sense) comprises different socially constructed artifacts, some of which may be "working" while others are "nonworking." I am not primarily making a metaphysical claim here—I am stressing this point because in this way the descriptive model will allow for a symmetrical analysis of technology, as called for in chapter 1. This is analogous to arguing that "Nature" should not play a role as *explanans*, as David Bloor (1973, 1976) did in his strong programme.[66] "Nature" should not be invoked to explain the truth of scientific beliefs; and neither should specific sociological circumstances—such as the scientist being excessively ambitious, having a bad marriage, or living under a totalitarian regime—be used exclusively to explain the falsity of scientific beliefs. This "symmetry principle" calls for sociologists analyzing scientific development to be impartial with respect to the truth or falsity of scientific beliefs. They should explain truth and falsity symmetrically, that is, by using the same conceptual framework.

Thus I want to argue that the account of bicycle development can be adequately rephrased by distinguishing two separate artifacts: the Unsafe Bicycle and the Macho Bicycle. Although these two artifacts were hidden within one contraption of metal, wood, and rubber (the so-called Ordinary), they were not less real for that. This can be seen from the different designs spectrums they to which they belonged. The Unsafe Bicycle gave rise to a range of new designs that sought to solve the safety problem. Many of these efforts were described in the previous section: moving the saddle backward (Facile, Xtraordinary), adding auxiliaries (the "Non-Header"), reversing of the positioning of small and large wheels (Star), or making other radical changes to the basic scheme (Lawson's bicycle). The Macho Bicycle developed in the opposite direction: the front wheel was made as large as possible. This design trend produced important and lasting effects in bicycle technology, even though the high-wheeled Penny-farthing became obsolete in the end. The making of higher wheels, for example, necessitated the development of better (and specifically, stiffer) spoked wheels. To distinguish two different artifacts in this way is more straightforward than trying to cope with the wide spectrum of different designs, even though one needs some imagination to see them within that one Ordinary.

I will call this sociological deconstruction of the Ordinary into an Unsafe Bicycle and a Macho Bicycle "demonstrating the interpretative flexibility of the Ordinary." The possibility of demonstrating the interpretative flexibility of an artifact by deconstruction implies that there is an immediate entrance point for a sociological explanation of the development of technical artifacts. If no interpretative flexibility could be demonstrated, all properties of an artifact could be argued to be immanent after all. Then there would be no social dimension to *design*: only application and diffusion—or *context*, for short—would form the social dimensions of technical development. But demonstrating the interpretative flexibility of an artifact sets the agenda for a social analysis of the design of technology as formulated in the "working as result" requirement for a framework.

Indeed, demonstrating the interpretative flexibility of an artifact can only be the first stage in a social analysis of technical design. The sociological deconstruction of an artifact leaves the sociologist's desk full of pieces that have to be put together again. After all, the analyst may deconstruct the Ordinary into two artifacts, but that does not change the fact that late nineteenth-century English society eventually did construct the high-wheeled bicycle into *one* black box, eliminating the Macho Bicycle and focusing development efforts on the Unsafe Bicycle, thereby preparing the way for the Safety Bicycle. Thus the demonstration of the interpretative flexibility sets the agenda for a sociological analysis of technical development. Once an artifact has been deconstructed into different artifacts,[67] it is clear what has to be explained: how these different artifacts develop; whether, for example, one of them peters out while the other becomes dominant. In the bicycle case, the "Macho," although dominant in the beginning, was in the end superseded by the "Unsafe," and the Ordinary thus developed from a working into a nonworking machine. In the next sections I will follow this process in the case of the safety bicycle.

Relevant social groups do not simply see different aspects of one artifact. The meanings given by a relevant social group actually *constitute* the artifact. There are as many artifacts as there are relevant social groups; there is no artifact not constituted by a relevant social group. The implications of this radically social constructivist view of technology will be addressed in the remainder of this chapter, especially in the third intermezzo, section 2.9. Then I will discuss how the "pluralism of artifacts," brought to the fore by demonstrating the interpretative flexibility, will eventually be reduced again, when one of the artifacts stabilizes.

2.8 The Air Tire

In 1845 William Thomson, a civil engineer of Adelphi, Middlesex, had already found what we now view to be the solution of the vibration problem (see figure 2.24). He patented "elastic bearings round the tires of the wheels of carriages, for the purpose of lessening the power required to draw the carriages, rendering their motion easier, and diminishing the noise they make when in motion," (Thomson, 1845: 2). He did so by using "a hollow belt composed of some air and water tight material, such as caoutchouc or gutta percha, and inflating it with air, whereby the wheels will in every part of their revolution present a cushion of air to the ground or trail or track on which they run" (ibid.). One of the ways, specified by Thomson in his patent, to make this elastic belt was to cement together a number of folds of canvas with india rubber, then render the belt more pliable by immersing it in melted sulphur, and finally, provide a strong outer casing by sewing circular segments of leather around the tire. Pipes were provided, passing through the wheel