An Analysis of the Role of Cycling in
Sustainable Urban
Mobility

# An Analysis of the Role of Cycling in <br> Sustainable Urban Mobility: 

The Importance of the Bicycle

By
Ricardo Marqués

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To my family, Asun and Ricardo

And to all my friends of 'A Contramano'

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## FOREWORD

Readers of this book are setting out on an interesting adventure as well as an incredible learning experience. Professor Ricardo Marqués provides a comprehensive examination of the past, present, and future of cycling. The main purpose of the book is to examine how cities can make cycling a mainstream mode of daily, utilitarian travel, even if they have no historical cycling culture, are car-oriented, and have very little, if any, cycling infrastructure to start with. "An Analysis of the Role of Cycling in Sustainable Urban Mobility: The Importance of the Bicycle" superbly achieves that purpose, while providing an extraordinary wealth of information on other aspects of cycling and the bicycle itself.

In his introduction, Professor Marqués invites readers to skip Chapter One if they are not interested in the bicycle's history and physics. Following his advice, I did just that, but I am very glad indeed that I went back and read that chapter. Indeed, I read Chapter One twice because it was so full of new information for me. I probably learned more from that chapter than any other part of the book. That is because I had known so little about the detailed history of the bicycle's evolution over nearly two centuries since the invention of the first crude prototype of the bicycle in 1817, with dozens if not hundreds of different kinds available for purchase now. Moreover, I knew nothing at all about the physics of how a bicycle operates and why it is about three times as energy-efficient as walking and fifty times as energyefficient as the average car.

Thus, my advice to readers is not to skip Chapter One, but to read it first, just as it appears first in the book. That chapter provides an excellent foundation for the rest of the book. Although it contains much technical information, Prof. Marqués does a superb job of presenting the information in a clear and understandable way that is accessible to readers (such as myself) with no technical background at all. As I discovered, Chapter One is far more interesting and informative that I could have imagined.

My own background is in urban transport planning and policy research, and for the past twenty years I have focused on the same cycling issues that Prof. Marqués examines in subsequent chapters of the book. Thus, I was
especially impressed by the author's insightful, well-organized, and clear exposition and analysis of the wide range of cycling infrastructure, programs, and complementary policies necessary to make cycling safe, feasible, and appealing for all social groups. Moreover, Marqués provides a fully international perspective, with specific examples and illustrations from dozens of countries on six continents. The book's description of various kind of cycling infrastructure benefits greatly from the author's technical background in physics and engineering. Using diagrams, photos, charts, and tables, Marqués provides a clear and easily understandable explanation of each type of infrastructure option and in what circumstances it is appropriate. City and transport planners and engineers will find this part of the book an extraordinarily useful and practical guide to building cycling systems in their own cities. That is perhaps the most important strength of this book: practical, easily understandable, comprehensive, and well-organized advice for anyone involved in planning for cycling-friendly, sustainable cities.

In addition to cycling infrastructure, the book includes a detailed analysis of the wide range of complementary programs and policies that are necessary for cycling to become a mainstream means of travel feasible for almost everyone. Some examples of supportive programs are cycling training, bikesharing, bike parking, integration of cycling with public transport, celebratory bike rides and regular mass cycling events such as Ciclovías.

Marqués emphasizes the crucial importance of car-restrictive policies as well. To improve traffic safety for cyclists and pedestrians, it is essential to traffic-calm most residential neighborhood streets by imposing speed limits of $30 \mathrm{~km} / \mathrm{h}$ or less. Such traffic-calmed neighborhoods can be found in hundreds of cities around the world. Extensive scientific research has shown that the most important benefit of traffic calming is that it dramatically reduces child injuries and fatalities from traffic, while increasing rates of child walking and cycling and enhancing the recreational possibilities for children in their own neighborhoods. Indeed, such streets are made less stressful, more pleasant, and more usable for residents of all ages. Trafficcalming also reduces air pollution and noise from motor vehicle traffic, thus making such neighborhoods healthier and more livable. Many northern and central European cities have embedded smaller 'home zones' within some of those traffic-calmed neighborhoods. Also called 'shared streets' or 'play streets,' such home zones lower speed limits even further, ranging from 10$20 \mathrm{~km} / \mathrm{h}$. The intent is to make those designated streets open for children to play and for all residents to enjoy as if they were extensions of their front yards, sort of a neighborhood park right in front of their houses. The lower
speed limits in traffic-calmed neighborhoods and home zones are passively enforced by altering roadway design through road narrowing, speed humps, raised intersections and crosswalks, traffic circles, artificial dead-ends for cars (diverters), and curves (chicanes). Such measures not only reduce speeds but also volumes of motor vehicle traffic in residential neighborhoods since they greatly deter through traffic, which does not belong in residential neighborhoods anyway. The book includes a detailed examination of traffic calming measures.

Most readers will be especially interested in the author's detailed, firsthand experience with the transformation of his hometown Seville, Spain from a city where cycling was a marginal, hardly recognized means of travel to a mainstream way to get around Seville for daily, utilitarian purposes, used by women as well as men, all age groups, all income groups, and all ability levels. In short, the conversion from cycling for a few to cycling for everyone. And that should be the goal of any city's transport policy. The indepth case study of Seville provides a wide range of lessons that can be applied to other cities around the world. Marqués explains the historical, cultural, economic, and political factors that influenced transport developments over various periods. Cycling planners, engineers, and public officials will obviously find useful the specific infrastructure, programmatic, and policy measures implemented in Seville over a few years to dramatically increase cycling. But even more fascinating is the political analysis of how public and political support was generated to support the financing and implementation of those measures, often involving removing roadway space from cars and shifting it to the bicycle. Car-restrictive measures are usually the most politically difficult to implement. Thus, the story of how it was done in Seville is both fascinating and useful for other cities trying to generate public and political support for new and controversial measures to promote cycling.

Whatever your background, whatever your profession, whatever your interest in bicycles and cycling, there is a wealth of information in this book that will interest you. For those readers who are professionally engaged in city transport planning and engineering, especially those dealing with cycling, you will find much practical information you can use in your profession. In short, this book has something to offer for anyone interested in any aspect of bicycles and cycling.

John Pucher<br>Professor Emeritus, Rutgers University, New Jersey USA

## INTRODUCTION

> 'A los cincuenta años, hoy, tengo una bicicleta.
> Muchos tienen un yate
> y muchos más un automóvil
> y hay muchos que también tienen ya un avión.
> Pero yo,
> a mis cincuenta años justos, tengo sólo una bicicleta.'

Rafael Alberti
'Balada de la Bicicleta con Alas'

The publication of this essay on the importance of the bicycle, which is an improved English-language version of a previous book written in Spanish ${ }^{1}$, comes more than 200 years after the construction of the first precursor to the bicycle, the draisine, invented in 1817 by Karl Drais in the German town of Mannheim, and more than 100 years after Lawson, Starley and Sutton built the first prototypes of the modern bicycle. Despite the fact that the bicycle is definitely not a recent invention, it is increasingly becoming a symbol of modernity throughout the world, especially in post-industrial cities and metropolises, where the abuse of motorised mobility has led to unsustainable situations of congestion and pollution that, periodically and with increasing frequency, are reported on in the mass media.

What makes such a comparatively old mode of transport still so modern in the truest sense of the word?

When one rides a bicycle in the city, one establishes a relationship very different from that experienced by the user of any mode of motorized transport. A cyclist, wandering around the city, can smell it, hear it, perceive it and, at the end of the ride, can get off the bike and continue walking alongside it. Thus, the cyclist may stop to chat with a friend, to buy a newspaper, some fruit or a cake, attracted by the fragrance of the pastry. In short, the cyclist immerses himself in his city in a very similar way to how

[^0]a pedestrian does, although enjoying a longer route. That is why as citizens around the world begin to consider not how to simply survive, but how to live in their cities, they turn their eyes towards the bicycle as the ideal way to embrace the whole city again, without losing quality of life or becoming mere spectators of the lives of others through the windows of their cars. Consequently, the bicycle, which is also the daughter of the industrial revolution, becomes the ideal vehicle to give back to cities the human scale that the industrial revolution itself snatched away from them by turning them into motorised metropolises.

But if the massive use of the bicycle is to help to return human scale to post-industrial cities, the city, in turn, must be returned to the bicycle, which will not be an easy task because, although bicycles were the predominant vehicles in most of the industrialised world during the 1930s, 40s and 50 s , the automobile boom has reduced them to insignificant percentages of the modal split in almost all of the world's cities, with the exception of a few that we all know and admire. It is easy to understand why: the bicycle is a machine and, as such, is often unwelcome on the pavements next to pedestrians. Nor does it enjoy the power and speed of a motor vehicle, so its accommodation in the road, next to such vehicles, is not easy, although for reasons opposite to the previous case. The result is that the bike has run out of space in cities. And, of course, space is the most precious commodity in a city.

When I say that the bicycle needs to recover its place in the city, I do not mean only in the public road, but generally speaking in the whole city (workplaces, parks, neighbourhood communities, businesses, places of study and leisure, public transport... ) including in the minds of its inhabitants. In fact, the latter is perhaps the most important because, although there is today some consensus on the benefits of cycling as a mode of transport, the bicycle is still seen as little more than a complementary vehicle when it comes to developing mobility policies. The main thesis of this essay is, however, that from politicians and planners to ordinary people, we must all become aware of the importance of utilitarian cycling (hence the title of this book) as an essential component of any project of sustainable and healthy urban mobility. Personally, I am convinced that, without massive use of the bicycle, it is not possible to advance in practice towards that goal. And that is what I hope to be able to demonstrate in this book.

As for its contents, this book draws on the experience of the University of Seville free choice subject "The Bicycle and Sustainable Mobility",
which the author coordinated from the 2007-08 academic year until the umpteenth reform of university education in Spain ended free choice subjects in 2015. The materials for this course provided a first basis for the elaboration of this book, which were later supplemented by further research and reflections.

I must also say that this book would not have been written if it were not for the remarkable experience recently developed in Seville, the city where I have lived and worked for more than 40 years. In just 5 years, Seville went from a city where the use of the bicycle was hardly perceptible to a place where the consolidated presence of this mode of transport in its daily mobility is a reality, with tens of thousands of users cycling through its streets and causing a change in the urban landscape that is obvious to the naked eye. This experience, to which I have devoted a chapter, motivated me, in part, to write this book.

Just a few words about terminology before describing the contents of this book. The word bicycle is used throughout this book in the etymological sense of the term: a two-wheeled cycle or, more precisely, a humanpowered vehicle having just two wheels situated in the same plane, one behind the other. This excludes unicycles, tricycles and quadricycles, which have sometimes also been named and studied as bicycles, but I shall also use the word to include all kinds of modern bicycles, as well as their predecessors, such as the draisine and the michauline. As will be summarized in Part II of the First Chapter, bicycles show relevant physical advantages over other cycles. It is probably for this reason that the bicycle is the most popular and relevant human-powered vehicle. Only in the specific field of cycle-logistics do tricycles and other bicycle-related vehicles become relevant and, consequently, they will also be considered in this book.

The book is organised as follows: Chapter One briefly describes the history and physics of the bicycle. It is one of my deepest convictions that nothing is truly understood until its history is known, at least in a summarized way. This is even more true when we are dealing with a human invention like the bicycle, which dates back more than 200 years. As for the physics of the bicycle, I was at first unsure as to whether or not to include it in the book but, being a physicist, it would have seemed somewhat disrespectful to myself not to include something about the physics of the bicycle, which in many ways helps to explain why the bicycle is so useful and convenient as an urban mode of transport. Two main questions will be
addressed from this perspective in that part: the stability and efficiency of the bicycle, both of which have a high impact on its usefulness as an urban mode. I have tried to do this in such a way that it will be understandable to the average reader and, of course, without using any complex formulae. If, in spite of this, I have not achieved my goal, the reader can simply skip this part, which will not be an impediment to the correct understanding of the rest of the book.

In Chapter Two, I try to describe the dead-end street to which the dominant policies of mobility, based on the petrol-fuelled automobile and its technological sequels, such as biofuels and electric cars, have led us. I analyse the reasons why these policies succeeded in the past, the problems they are now causing and how they have become the most unsustainable and unhealthy aspect of the current way of life in the so-called 'developed' countries. This analysis includes, as well as the physical and ecological limits faced by the dominant model of urban mobility, the difficult social and public health problems it creates.

Chapter Three is possibly the crux of this book. It describes the potential of urban cycling as an essential and unavoidable element of any urban mobility policy aimed at sustainability, and it answers the key question about the role, in my opinion, essential, that the bicycle can and should play in the transition towards a sustainable urban mobility model. Two key questions that must be faced by any policy of promotion of the bicycle as a mode of transport are then addressed: what should its place be in public roads and how can a comprehensive approach be given to the policies of road safety in relation to the bicycle.

Chapter Four, while not meant to be a manual, is dedicated to describing in a global way the main concepts and techniques of promoting cycling mobility in the urban environment. There have been many experiences that have failed because they lack a holistic vision and focus only on specific and not always essential aspects of the problem. When to integrate and when to separate bicycles from motorized traffic? What essential characteristics should a network of cycle paths have? When is the coexistence of bicycles and pedestrians possible? How to effectively combine cycling and public transport? What aspects determine the success of a public bicycle system? What complementary infrastructures does the bicycle need to thrive? How to socially integrate the bicycle in the city? These are all essential issues that need to be assessed before undertaking a minimally successful bicycle promotion programme.

Finally, Chapter Five describes and critically analyses a successful example of urban cycling promotion in which the author had the opportunity to participate. Seville has been the scenario of a successful experience of urban cycling promotion, starting practically from zero. This experience may be inspiring for many other cities in the world sharing a similar starting situation (in fact, unfortunately, most of them). What were the differential factors that led to success in Seville? Which are the bottlenecks presently faced by urban cycling in the city? How can they be overcome?

The book ends with some final remarks and with a bibliographical appendix compiling the references cited throughout the text.

I am indebted to the Editorial Universidad de Sevilla for allowing for the reproduction of much of the material which originally appeared in the first Spanish version of this book. I am especially grateful to Prof. John Pucher of Rutgers University for reading the book, writing the foreword and making very useful suggestions. I am also grateful to Manuel Calvo-Salazar and Vicente Hernández-Herrador for making useful comments and providing many photographs. Francisco Manuel García-Farrán, Elena Huerta, Juanma Mellado, 'Okocycle' and 'Santa Cleta' also provided photographs and graphic material for the book. I should also like to thank the Bicycle Office of the Municipality of Seville, and especially Emilio Minguito and Javier Huesa, for providing invaluable graphic material and information for Chapter Five. Special thanks are also given to James Langford, who revised the English text and made many corrections.

## Chapter One

## The History and Physics of the Bicycle

'The development of the bicycle is a long love-affair between the human body and mechanical ingenuity.'

Andrew Richtie
'King of the Road' (1975)

## Part I: The invention of the bicycle: from the draisine to the safety bike

The earliest precedent of the bicycle which has written records ${ }^{2}$ is the célerifère, supposedly invented by the French aristocrat Mede de Sivrac in the middle of the French Revolution (Baudry de Saunier, 1891, pp. 4-8; Richtie pp. 17-18). The célerifère was nothing but a rigid frame of wood, to which Sivrac coupled two wheels and provided with a saddle and a fixed handlebar. The célerifère was impelled by means of strides, alternately supporting the feet on the ground and pushing. The célerifère did not have any type of steering mechanism, a fact which would certainly make its handling quite uncomfortable, turning it into a toy rather than a true means of transport. This absence of a steering mechanism implies, as will be seen below, that the driver of the cellerifère would need the support of his feet to keep his balance. Therefore, the célerifère was not a true bicycle.

[^1]More recently, bicycle historians (see, for instance, Seray, 1988, pp. 1317) put into doubt the the historical existence of the célerifère, attributing its 'existence' to a misconception propagated in 1891 by the aforementioned French journalist and historian of the bicycle Louis Baudry de Saunier. In any case, the célerifère was for many years considered to be the first case of a bicycle having written record, and as such deserves to be cited. On the other hand, the basic idea of the célerifère - to couple a pair of wheels to a frame - is so simple and evident that it seems more than plausible that designs similar to the célerifère may have been conceived and even constructed more than once throughout the history of mankind.

What there can be no doubt about is the invention of the 'draisine' in 1817 by Karl Drais von Sauerbronn in the german city of Mannheim (see, for instance, Seray 1988, pp. 19-47 or Herlihy 2004 pp. 19-30). The existence of this 'laufmaschine' or 'running machine', as its inventor called it, is perfectly documented and all bicycle historians agree on this. The draisine can be described as a célerifère whose front wheel incorporates a steering mechanism, that originally resembled more the tiller of the helm of a ship than a modern handlebar. The incorporation of this steering mechanism to the draisine made it much easier to ride than the célerifère (if it did exist), allowing the rider to maintain his balance independently of his stride (by making small turns on either side, as will be explained in Part II of this Chapter). Thus, whereas the rider of the célerifère, had to use his feet as much to keep his balance as to move forward, the rider of the draisine used them only to move forward, which is why one could 'keep them both in the air, to take a rest, while the machine rolls at high speed', as is stated in the text of the French patent requested by Karl Drais in 1818 (cited by Seray 1988, p. 37).

A few years later, in 1819, the English coachmaker Dennis Johnson developed an improved model of the draisine, the so-called 'hobby-horse' (see, for instance, Herlihy 2004, pp. 31-38, Richtie pp. 20-27). Dennis Johnson introduced the handlebar and other steel parts, and even developed a version of the hobby-horse for ladies, with a step-through frame so that they could easily accommodate their long skirts, in what can be considered the first precedent of ladies' bicycles (Woodforde 1970, pp. 10-11; The Online Bicycle Museum n.d.).

Johnson and his company, Swift Cycle \& Co. Ltd., had some success, selling between 300 and 400 hobby-horses, mainly among the dandies of London. However, conflicts soon began to emerge. Some pedestrians
thought they were being attacked by this new vehicle and its sometimes anarchic drivers, who invaded the pavements searching for a smoother surface, which resulted in criminal cases with fines being given to some of the most daring and/or inexperienced drivers and, finally, in the banning of hobby-horses on pavements. To make matters worse, the London College of Surgeons issued serious warnings about the health problems that could result from a continued use of hobby-horses, such as severe hernias or cramps (Herlihy 2004, p. 38), in what can be considered the first precedent of the prejudices that have accompanied the use of the bicycle ever since. Whether it is because of these causes or just because the fashion ended, the truth is that sales plummeted and the hobby-horse boom ended around 1821.


Figure 1.1: The draisine is still present in our lives as a toy that many boys and girls use to practise keeping their balance and to get started in bicycle riding.

If making the balance independent from the stride by incorporating the steering mechanism was the starting point of the bicycle, the next challenge to be solved was to separate the progression of the stride, so that it would not be necessary to put a foot on the ground to propel the bicycle. Riding a draisine or a hobby-horse could be considered as an activity halfway between walking and cycling as we understand this latter activity today. In
fact, we have already commented that the name Karl Drais gave to his invention was that of 'laufmaschine' or 'running machine', and hobby-horses were also known in England as 'swift walkers'. But the efficiency of the stride as a propelling mechanism decreases drastically as speed increases. This can be easily understood by taking into account that the speed relative to the ground of the foot is the difference between its speed with respect to the draisine and the speed of the draisine itself with respect to the ground. Thus, as the draisine acquired speed, its occupant had to increase the speed and frequency of his strides; otherwise, the impulse obtained from each stride would vanish. Clearly, this has a biomechanical limit, which is reached fairly soon. To overcome this drawback, it was necessary to imagine a propelling mechanism whose efficiency did not depend on the speed of the vehicle, which can only be achieved if the driving force is applied directly to the wheel, instead of to the ground. The first step in that direction seems to have been taken by another Englishman, Lewis Gompertz, who in 1821 proposed an ingenious mechanism to power the front wheel of the draisine by using a hand lever connected to the wheel by a gear (see, for instance, Seray 1988, p. 64). But nothing came of it.

Many books and articles devoted to the history of the bicycle mention the attempts made in Scotland to endow the draisine with a propelling mechanism applied to the rear wheel by using connecting rods and cranks (see, for instance, Richtie, pp. 34-37). The mechanism would be similar to the one used by the newly invented steam locomotive of George Stevenson. Kirpatrick McMillan is claimed to have applied such mechanism to the rear wheel of a draisine in 1839. However, the first documented reference to this is the velocipede built in 1869 by Thomas McCall, which is conserved in the Museum of Science of London (Herlihy 2004, p. 68). Therefore, McCall's velocipede would have been built after the invention of the front wheel pedal drive in France.

McMillan/McCall's velocipede had a rear wheel which was somewhat larger than the front wheel and was propelled by connecting rods and cranks applied to it. The connecting rods were in turn connected to two vertical bars hanging from the frame, with pedals on its opposite ends (see Figure 1.2). The rider of the velocipede pushed the connecting rods back and forth by swinging his legs on the pedals, thus propelling the velocipede forward. It was, in essence, the same mechanism that propelled the first steam locomotives, except that the driving force did not come from a piston driven by steam pressure, but by the cyclist's legs. However, McMillan/McCall's velocipede, while solving the problem of the transmission of the force to the
rear wheel, generated other problems. First, the leg-swinging movement needed to propel the velocipede is not entirely efficient from a biomechanical point of view (Navarro 2010, p. 27). Second, swinging the legs back and forth in order to propel the velocipede hampers the steering of the front wheel, generating a conflict between the propulsion and the steering of the vehicle (Richtie 1975, p. 36; Navarro 2010, p. 27).


Figure 1.2: Schematic representation of a draisine (a), the velocipede of McCall (b), a michauline (c) and the 'bicyclette' of H. J. Lawson (d), precedent of the 'safety bike'.

Presently, many bicycle historians (Seray 1988, pp. 65-67; Herlihy 2004, pp. 66-71) grant little credit to McMillan's vindication and attribute directly to McCall the idea of endowing the draisine with rear propulsion through connecting rods and cranks, in the image and likeness of a locomotive. It is even possible that McCall's invention was inspired by earlier tricycles or quadricycles that used this kind of propulsion, which was much more suitable for such vehicles than for a bicycle, where the conflict with the steering mechanism seems difficult to avoid (see Fig. 1.2).

There are other claims related to the introduction of a rear transmission for the drasine based on levers and/or connecting rods and cranks, such as
those of another Scot, Gavin Dalzell, (Seray 1988, pp. 65-68) or the French emigrant to California, Alexandre Lefebvre (ibid., p. 69) ${ }^{3}$. But in any case, whether or not these claims were true and/or prior to the transmission by means of pedals attached to the front wheel, the fact is that they did not have any influence on the subsequent development of the bicycle, although, in the end, the transmission to the rear wheel triumphed, but not by levers or cranks, but by a chain, as we will see later.

The introduction of pedals directly coupled to the front wheel of the bicycle took place in France during the 1860s. Although historians differ as to the precise date of the invention and the role played by each contributor (There is some controversy on this point. See, for instance, Seray 1988, pp. 71-96 and Herlihy 2004, pp. 75-101.), it is clear that the invention and its first developments must be attributed to the Parisian blacksmith Pierre Michaux and his son Ernest, to the brothers René and Aimé Olivier, or to Pierre Lallement, who patented the invention in the United States. In 1867 Michaux and the Olivier brothers founded in Paris the first factory of 'michaulines' ${ }^{\prime 4}$ on the two upper floors of the Michaux workshop in Paris. Almost simultaneously, Lallement patented a similar invention in the United States in 1866. The genially simple idea of the Olivier brothers, Michaux and Lallement was to couple two pedals to the front wheel of a draisine, by means of a pair of cranks directly attached to the wheel axle. The front transmission allowed a much more efficient movement of the legs from a biomechanical point of view and, at the same time, prevented the conflict between propulsion and steering of McCall's velocipede. Michaulines were very successful: Hundreds of copies a year were made first in France and then in Britain (where they were nicknamed 'boneshakers' due to their rather rough ride), the United States and Germany by various manufacturers, who also introduced some improvements.

It can be wondered why the idea, in principle quite simple, of coupling two pedals to the front wheel of a draisine took more than forty years to develop. Indeed, many people asked themselves this question after the michauline was developed. A stunned editor at the New York Clipper, writing in the fall of 1868 , described the new pedals as a 'mechanism so

[^2]simple that everybody wonders [why] they had not thought of it before.' (Herlihy 2003, p. 47). Herlihy attributes this fact to the already mentioned 'hostility' of the public towards the draisine, which prevented further developments. We may also consider that the reason might have also been psychological: To imagine for the first time that it was possible to maintain one's balance on two wheels without putting one's feet (or additional wheels, as in tricycles and quadricycles) on the ground at any time would not be easy.

The michauline was the first truly popular bicycle. In May of 1868, 'Michaux \& Co.' sponsored the first official cycling races in Paris, which inspired other contests that summer in and around the French capital (Herlihy 2004, p. 96). The use of the velocipede also became popular amongst women, and in November of that same year, the first women's cycling race took place in Bordeaux with thousands of spectators present (Herlihy 2004, p. 100). The craze soon extended beyond the sea to the United States, where the michauline became so popular that a journalist proposed building an elevated cycle path to run the entire length of Manhattan, probably the first proposal for a bikeway ever made (Richtie 1975, p. 66).

Nonetheless, the michauline was still a vehicle for the rich. Its cost, between 200 and 250 francs, was high for the middle class, and unaffordable for the working class. Voices were raised calling for the manufacture of velocipedes made for the working class and not simply for the amusement of the rich. 'The velocipede will amuse the idle rich for a while, but they will abandon it one day, for the simple reason that they all own horses and carriages. The velocipede will thus become the carriage of the poor. That is its true destiny', wrote a journalist of the time with unquestionable historical vision (cited by Herlihy 2004, p. 130).

Despite their success, the michauline still had a serious technical problem: The short distance travelled by each pedal stroke of the cyclist. Both in the michauline and in McCall's velocipede, the distance $d$ travelled by each pedal stroke could not be other than the total length of the circumference of the wheel receiving the impulse, i.e. $d=2 \pi r$, where $r$ is the radius of the wheel. In the case of the michauline, although its front wheel was larger than the rear wheel, to actually alleviate this problem, the distance advanced by each pedal stroke was not much longer than 3.14 metres (for typical wheels of 1 metre in diameter). For the sake of comparison, a typical modern bicycle advances between 7 and 9 metres by each pedal stroke.


Figure 1.3: With the arrival of the high-wheelers, which were unsuitable for ladies, tricycles became very popular amongst them, while bicycles were used by young and athletic gentlemen. In the photo, members of the 'Club Velocipedista El Porvenir' (Seville, Spain), in 1890. Source: Memorias de Sevilla.

As a result, michaulines were slow and pedalling was tiring and inefficient. The maximum speeds attainable on a michauline were determined by the cyclist's pedalling pace which, for biomechanical reasons, could not be much higher than one pedal stroke per second. Therefore, the maximum speed
of a michauline with a front wheel of one metre in diameter cannot be much higher than $11 \mathrm{~km} / \mathrm{h}$. Thus, for example, in the first Paris-Ruen race, held in 1869, the winner, the Englishman James Moore, rode the 123 kilometres between both cities in 10 hours and 40 minutes, at an average speed of approximately $12 \mathrm{~km} / \mathrm{h}$ (Richtie 1975, p. 60), a speed that is now easily exceeded by any urban cyclist, regardless of their physical fitness. As for the fatigue caused by pedalling, the reader can get an idea of it by riding a commercial 27 -speed mountain bike and trying to advance by pedalling with the chain on the smallest chainring and the largest sprocket.

Following the basic design of the michaulines, the only way to increase the distance travelled with each pedal stroke was to increase the radius of the front wheel. Thus began a race towards the construction of bicycles with larger and larger front wheels, the so-called 'high wheelers's, which incidentally raised interesting engineering problems linked to the manufacture of large wheels with the necessary resistance and flexibility which led to technological innovations such as tensioned wire spokes. The front wheel of high wheelers eventually reached a diameter of around 60 inches (about 50\% larger than a typical michauline's front wheel). It was not possible to go much further, both due to the difficulty of driving the velocipede and the limitations imposed by the cyclist's anatomy. Although ingenious solutions were attempted, including lever extensions to the pedals such as in the 'Xtraordinary' and the 'Facile' designs (Seray 1988, pp. 121122), both in 1878, and chain transmission to the front wheel, such as in the 'Kangaroo' (Seray 1988, p.120) of 1884, the time of the high wheelers was coming to an end.

The high wheelers, on the other hand, were expensive and difficult to ride, so their potential market was limited to young, rich and athletic men, largely excluding women, middle-aged men and most working class people, who were not able to afford a high wheeler, unless it were a second-hand model. Then began a golden age for tricycles and quadricycles of one or several seats, which were used by ladies, middle-aged gentlemen and couples, although, for obvious reasons, these machines were still more expensive than bicycles and, therefore, even more difficult for workers to afford. The democratic spirit of the first michaulines was lost, and replaced by an aristocratic and elitist spirit.

[^3]The solution to all these problems came in the form of chain transmission to the rear wheel ${ }^{6}$. The transmission chain was invented by Leonardo da Vinci, who produced several drawings in which this transmission mechanism was applied to several devices, although not to a bicycle, whose concept was unknown to him, as we have seen. It seems that the chain transmission was first applied to some tricycles which, as we have mentioned, experienced a huge expansion during the high wheeler era. In 1879, Henry J. Lawson patented a bicycle driven by a chainset connected to a sprocket on the rear wheel by a chain, which he called the 'bicyclette' (see Figure 1.2). This was the first precursor of the modern bicycle ${ }^{7}$.

Lawson's bicyclette had little success, but in 1885 John Kemp Starley and William Sutton developed an improved model of Lawson's bicyclette, which they called the 'Rover Safety Bike' or, in short, the 'safety', whose name indicates its biggest advantage over the high wheelers: safety. Although the first models had a somewhat different design, the safety bike soon evolved, and by 1900 their basic design was already that of a modern bicycle, with wheels of similar $\operatorname{size}^{8}$, a diamond frame and a steering mechanism which was attached directly to the front fork (see Figure 1.4).

The safety bike solved the aforementioned problem of the small distance advanced by the michauline with each pedal stroke by introducing a new variable in the formula giving this distance: The 'gear ratio', i.e. the ratio between the number of teeth in the chainring $N$ and the number of teeth in the rear wheel sprocket $n$, so that $d=(N / n) 2 \pi r$. It is apparent that now the distance travelled with each pedal stroke can be increased, in principle indefinitely, by just increasing the gear ratio ( $N / n$ ). This solution was much safer and more economical than increasing the size of the front wheel.

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Figure 1.4: Safety bike (France, around 1900) with front lantern and fixed rear sprocket showing a design quite similar to present bicycles. The head angle and the trail are marked. Photograph of the author, bicycle courtesy of Santa Cleta (Seville).

The safety bike had a resounding success, to which women, whom the high-wheelers had relegated to riding tricycles, contributed in no small way. Some manufacturers recovered Dennis Johnson's old idea and began to design safeties for ladies. However, many women opted for the simpler and more direct solution of wearing trousers. By 1850, the feminist Amelia Bloomer had introduced the fashion of 'bloomers' in the United States, while in 1881 Lady Harberton introduced the divided skirt in England. Both innovations became enormously popular with the arrival of the bicycle and its widespread use by women (Herlihy 2004, pp. 138-139 and 266-271). Thus, during the 1890s the enormous success of the 'safety' among ladies generated a wide debate about what kind of clothing women should wear on a bicycle (see, for instance, the interesting contemporary testimony of F. J. Erskine, 1897), which helped the revolution in women's clothing and transformed the bicycle into a symbol of women's liberation. As an example of this link between the bicycle and women's liberation, when in 1897 the University of Cambridge decided to admit female students, part of its male students organised a protest during which they symbolically hanged the mannequin of a woman riding a bicycle, as an example of the kind of woman they did not want to have in 'their' university (Macy 2011, p. 76). By the end of the 19th century, the bicycle and women's liberation were inextricably linked and the American civil rights leader, Susan B Anthony, said in 1896:
'I think [the bicycle] has done more to emancipate women than anything else in the world. I stand and rejoice every time I see a woman ride on a wheel.' (cited by Macy 2011, p. 77).

By 1890, the safety bike already dominated the market and all the surviving manufacturers had incorporated it into their catalogue. Thanks to mass production, the safety had gone from being a toy for the rich to being a utilitarian product for mass consumption. With the safety bike the history of the modern bicycle begins, something that we will see soon. But first we will make a brief interlude to better understand how this wonderful machine works.

## Part II: The physics of bicycle

The bicycle is a machine of complex behaviour whose dynamic balance and incredible stability defy intuition, and whose efficiency exceeds that of any other vehicle. For years it has been the subject of innumerable improvements and innovations that have given rise to the different bicycle models that are now on the market: the urban bicycle, the racing bicycle, the mountain bike, the hybrid, the folding bicycle, the recumbent bicycle, the cargo bicycle, and so on. The physics and engineering behind them is a huge field of research in continuous evolution which we cannot address here even in a summarised way. We will therefore limit ourselves to briefly answering two questions, possibly those which are the most relevant to our purposes and which most intrigue the general public. The first one can be formulated in a simple way: Why do cyclists not fall over? The answer to this first question will also tell us why a moving bicycle is so stable, even more than a tricycle, for example, which, in principle, is counterintuitive. The second question has to do with a key aspect for this essay: Why is the bicycle so efficient? Why, if a walker and a cyclist share the same driving force (that provided by their heart and muscles), is the cyclist several times faster than the walker, being able to travel with similar effort and in the same time four times more distance?

In 1869, just at the beginning of the bicycle craze in the United States, Scientific American pointed out 'That a velocipede should maintain an upright position is one of the most surprising feats of practical mechanics.' (quoted by Heirlihy 2004, p. 107). In fact, the bicycle only has two points of support; therefore, the static balance is impossible. So, it is apparent that cyclist's balance is a dynamic equilibrium, which only occurs on the condition that the system formed by the bicycle and the cyclist are moving. Reversing Albert Einstein's well-known sentence, we could say that the
bicycle is like life: to keep your balance, you have to keep moving forward.
According to what we might call the 'standard theory' of the cyclist's dynamic equilibrium, this is based on one of the fundamental laws of physics: the law of conservation of angular momentum. This law can be stated in a qualitative way by saying that every symmetrical body (for example a wheel) in rotation around its axis tends to maintain invariant said rotational movement, which includes the tendency to maintain its axis of rotation always in the same direction. In essence, this law is just one of the manifestations of the 'law of inertia' discovered by Galileo Galilei, whose statement marks the beginning of modern physics. The reader can get an idea of how the law of conservation of angular momentum affects the wheel of a bicycle by holding the axle of one of them with both hands (for this you can use one of those axle extensions or 'pegs' used by BMX lovers) as shown in Figure 1.5 (left). If you now ask an 'assistant' to spin the wheel quickly and, with the wheel in rotation, you try to change the orientation of its axis, you will notice that it offers some resistance, and the higher the frequency of the wheel's rotation, the more resistance there will be.

According to a first and rather naive version of this 'standard' theory, it would be this tendency of the wheels of a moving bicycle to maintain the orientation of their axis of rotation which would explain the cyclist's balance, at least while it is moving in a straight line. According to this theory, the célerifère described in part I of this chapter would be able to maintain its balance - at least for a certain time - if it is ridden in a straight line on flat ground, due to the aforementioned effect. However, this is not exactly so. If we simulate a célerifère by tying the handlebar of a bicycle so that it cannot turn and, after putting it upright, we give it a strong push forward, we will observe how the bicycle is able to travel a short distance before falling to the ground, although the experiment is quite disappointing because such a distance is too short to talk about the self-stability of the simulated 'célerifère' ${ }^{\prime}$. The shortness of this distance becomes apparent when we compare it with the distance that the same bicycle is able to travel with its handlebar free of ties ${ }^{10}$. In this last case, the bicycle can travel a much longer distance while tracing a wide curve on the ground. This behaviour is called self-stability of the bicycle. We will conclude, therefore, that the mechanism by which a cyclist acquires balance on a bicycle is a more complex issue than the simple tendency of the wheels to keep their axis of rotation unchanged. In this respect, and in view of the second

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[^0]:    ${ }^{1}$ Marqués, R. (2017) La Importancia de la Bicicleta. Ed. Universidad de Sevilla, Seville, Spain

[^1]:    ${ }^{2}$ In April of 1974 the news spread of the discovery of a drawing by Leonardo da Vinci (or of one of his disciples) that represented a bicycle. The resemblance to a modern bicycle was surprising, incorporating even the chain transmission which was, as will be seen, the last advance in the evolution towards the modern bicycle. Unfortunately, most experts now agree that this was a fraud: there are no other references to such a "bicycle" in all Leonardo's work, the style of the drawing is not recognizable and, to top it all, the ink was dated in a period well after Leonardo. See, for instance, (Navarro 2010, pp. 15-21) or (Penn 2010, pp. 100-103). Moreover, in the drawing there is not a clear steering mechanism (Roberts 1991, p. 18) which, as we will see later, is essential for balance and, therefore, for the device be properly considered a bicycle.

[^2]:    ${ }^{3}$ Curiously, the drawings we have of Dalzell and Lefebvre's machines (see, for instance, Roberts 1991, pp. 25-26) do not show the aforementioned conflict between propulsion and steering, apparent in McCall's velocipede.
    ${ }^{4}$ In fact, the name "michauline" did not appeared until more recently to refer to the Michaux velocipede (Roberts 1991, p. 29). I will use this name, however, in order to differentiate Michaux type velocipedes from other designs.

[^3]:    ${ }^{5}$ It was only after other bicycle designs appeared that the high wheeler was named as "ordinary", just to differentiate it from these other designs. The high wheeler was also nicknamed the "penny-fartingh" due to the very different sizes of its two wheels, which resembled the different sizes of these coins.

[^4]:    ${ }^{6}$ Apart from McCall's velocipede, the transmission to the rear wheel has a precedent in the "Star" bicycle (Seray 1988, p. 123) of 1880, which reversed the standard high wheeler configuration, by placing a small wheel in the front and a large wheel driven by levers in the rear.
    ${ }^{7}$ Although it is possible that there were some French and English precursors of Lawson's bicyclette (see, for example, Richtie 1975, pp. 122-124 and Seray 1988, pp. 125-131) they must have been, in any case, isolated embodiments of an artisanal nature, without any further influence on the bicycle industry, whose centre of gravity moved, after the Franco - Prussian War (1870-1871), from France to England.
    ${ }^{8}$ Probably as a souvenir of the michaulines, Lawson's bicyclette as well as the first designs of Kemp and Sutton still had a front wheel which was somewhat larger than the rear one, a characteristic that had no functional purpose and that disappeared in later designs.

[^5]:    ${ }^{9}$ The experiment con be seen in the video of A. Schwab (2011a).
    ${ }^{10}$ The experiment can be seen in the video of A. Schwab (2011b).

