The Bicycle*  
Engineering Marvel and Great Social Reformer  

Amitabha Ghosh

Bicycle—the machine that is perhaps most closely associated with our daily lives but the least understood since very few pay any attention to this constant companion. Bicycles have has a very colourful history and it has led to the development of many technological innovations, including automobiles. What is still less recognised is its contribution to some important social reforms, particularly women’s freedom from the domestic confines. This article presents a short account of these developments.

1. Introduction

It is well-recognized that wheeled transportation has played a vital role in the advancement of human civilization. The story of the origin of wheels is lost amid antiquity. However, the presence of wheeled vehicles in ancient civilizations has been established through the discovery of objects from archaeological sites of the Indus-Sarasvati civilization, dating back to the third millennium BCE. *Figure* 1 shows the model of a two-wheeled vehicle found from Harappa. It is also evident that, to begin with, man used two-wheeled vehicles (as seen in the figure). Four-wheeled vehicles came later. The fundamental difference between the ancient two-wheeled chariots and the bicycle is that in a bicycle, the two wheels are in the same vertical plane. It took a long time to figure out that such vehicles can remain stable without falling due to gravity.

Bicycles play a very intimate role in our daily lives. It is one of

*Vol 26, No.8, DOI: https://doi.org/10.1007/s12045-021-12110-4
Figure 1. Model of a chariot found in Harappa.

Bicycles have a very interesting and colourful history, which many of us are unaware of. The role played by this contrivance in social reform is also highly noteworthy. The most familiar machines to all of us, yet the least understood! Researchers are trying hard till date to unravel the mystery behind its dynamics. Bicycles have a very interesting and colourful history, which many of us are unaware of. The role played by this contrivance in social reform is also highly noteworthy. This article is an attempt to present the genesis of bicycles, their evolution and contributions to many new engineering concepts, their contributions to the development of automobiles, and finally, the major social transforms it triggered, particularly the social empowerment of women.

Before getting into details, it is desirable to present some technical aspects like the energy efficiency of this contrivance for transportation compared to other modes of travel and transportation. Figure 2a shows the specific energy consumption of various modes of travel and transportation. Figure 2b presents the efficiency of bicycles in comparison with other common engineering contrivances.

It is clear from Figure 2a that travelling by bicycle consumes minimum energy. Besides, it should be also noted that transport by bicycle causes the least pollution, and at the same time, it is good for health. Figure 2b shows the efficiency of the operation of a bicycle when compared to other motion generating machines and devices. In this aspect also, the bicycle is the most efficient, meaning that almost the entire input energy is used in producing the motion causing a minimum loss in the process. It will
be shown later that the development of the bicycle has resulted in several crucial engineering innovations that have helped other sectors of mechanical engineering.

However, the dynamics of bicycle motion is an extremely complex matter, and engineers and scientists are still trying to have a complete understanding of bicycle dynamics. Few references can be found in the bibliography. A detailed analysis is beyond the scope of this article. A very simplified analysis will be presented that can help our understanding of a few commonly observed phenomena while riding a bicycle.

The dynamics of bicycle motion is an extremely complex matter, and engineers and scientists are still trying to have a complete understanding of bicycle dynamics.
Genesis and Early Developments

It is known to all that “necessity is the mother of invention”. This was also the case with the invention of the bicycle, and it is an interesting story. To reach the root of the problem that led to this development, one has to go back two centuries in the past—the year 1815—to a small island of Indonesia—Sumbawa. In April 1815, the recorded history experienced the most violent natural phenomenon, the explosion of volcano Tambora. The top 4000 feet of this 13000 feet volcano blew off, throwing up about 100 km$^3$ of rock, dust, pumice, and 60 megatons of sulphur 40 km up into the atmosphere! It rapidly combined with the H$_2$ in the atmosphere, producing about 100 million tons of sulphuric acid. This eruption was more than ten times that of the Krakatoa eruption in 1883, and in devastating power, it was equivalent to 2000 megatons of TNT! Since the telegraph was not invented back then, the news of this eruption did not circulate, unlike in the case of Krakatoa. The eruption caused a disastrous effect on the global climate. In North America, Europe, and China, crops failed, resulting in famines, epidemics, and many social upheavals. In 1816 and 1817, there was no summer in Europe, and the continent was ravaged by severe winter, tempests, and extra heavy rains. However, some interesting results emerged from the imagination of contemporary writers. Percy Bysshe Shelley, Mary Wollstonecraft Godwin (Who later married Percy), Lord Byron, and John Polidori formed a friends group and took refuge in a Lake Geneva home in the summer of 1816. They experienced horrendous weather conditions, including severe tempests, incessant rains and flooding. In the dark halls, in those fearful nights without light, emerged two famous novels—Mary’s Frankenstein and Byron’s A Fragment, which Polidori developed into the famous The Vampyre, the predecessor of Dracula!

The severe famine condition across Europe made maintaining a horse very difficult. Besides, a very large number of horses perished making transportation a severe problem. In June 1817, Baron Karl von Drais of Baden, Germany, patented a two-wheeled device he called the Laufmaschine. It was created not out of
fancy, but out of necessity to replace horses. This device became known as Draisine and was reproduced in England, France, and even, the USA. It had different names, of course, such as ‘Dandy Horse’, ‘Hobby Horse’, and ‘Velocipede’. Figure 3a shows an artist’s impression of the device—a horse that does not eat grass. An actual model is depicted in Figure 3b. As can be seen in the pictures above, the machine was propelled by the rider’s feet. Though it looks like a clumsy arrangement, an expert in using the draisine could achieve a speed up to 15 km per hour. Thus in towns, where good roads existed, this became a popular device for going to office as can be seen in Figure 4. However, in many towns, the device was considered to be a hazard to the pedestrians, and the use of draisine was banned.

It took another decade before the riders could dare to take both the feet off the ground, and it was observed that the device could remain stable when in motion!

A Scottish blacksmith—Kirkpatrick McMillan—employed oscillating pedals to turn the rear wheel, thus making it a bicycle in the true sense as we understand it. It surprised everyone to notice that contrary to expectation while running, and if controlled properly, it did not fall. However, none of the above devices became successful commercially. Only in the 1860s, when Pierre Michaux and Pierre Lellemont designed a bicycle with pedals with the front wheel, a commercially viable device emerged. Figure 6 shows the contrivance. To have a reasonable speed for

**Figure 3.** The first draisine and an actual model of 1817.

Though it looks like a clumsy arrangement, an expert in using the draisine could achieve a speed up to 15 km per hour. Thus in towns, where good roads existed, this became a popular device for going to office. However, in many towns, the device was considered to be a hazard to the pedestrians, and the use of draisine was banned.
Figure 4. Office goers on draisine.

Figure 5. 1839 model of velocipede.

In the second half of the 19th century, the urge to develop bicycles became prominent as everyone realized its great potential. Stability, it became necessary to increase the radius of the front wheel. Thus this model with a large front wheel and a small rear wheel acquired the name ‘penny farthing’ as shown in Figure 7. Quite naturally, riding such a bicycle needed excellent skill, and accidents were quite frequent.

**Engineering Innovations and Safety Model**

In the second half of the 19th century, the urge to develop bicycles became prominent as everyone realized its great potential. A number of wonderful new ideas emerged out of this evolutionary process as presented briefly below.
1. Rear-wheel drive with chain and sprocket, reducing the size of the wheel rendering the bicycles ‘safe’.

2. The pneumatic inflated tube was introduced in 1890 by Dunlop, making the ride smoother.

3. Ball-bearings were developed to support the wheels.

4. Wonderful spoke–based wheels were innovated.

5. Energy-efficient chain–sprocket system was invented.

6. The freewheel concept emerged, making riding relaxing as the...
The thin spokes in the bicycle wheel are kept under pretension so that they do not buckle under the rider’s weight. Furthermore, to provide torsional rigidity to the rim-hub, the spokes are not radial but tangential to the hub.

Quite often, we fail to notice the wonderful concepts. The design of the spoked wheels is one good example. Not many are aware of the fact that the thin spokes are kept under pretension so that they do not buckle under the rider’s weight. Furthermore, to provide torsional rigidity to the rim-hub, the spokes are not radial but tangential to the hub as shown in Figure 8.

An interested reader can find the details of other innovations, which emerged out of the urge to improve upon the bicycle. Once the need for a large front wheel was eliminated, the rear wheel became the driving wheel at a higher speed (due to the crank-sprocket teeth ratio being more than unity). The model that was first brought to the market was called ‘Rover’s safety bicycle’, shown in Figure 9a. Soon after, other models started appearing in the market as this transportation mode was gaining popularity. Figure 9b shows another model of that time, and a quick examination of the model makes it clear that very little further change of the basic design had been possible, and the design had reached the near-optimum condition. Only changes had been in the material selection and a few other additional gadgets.

Figure 10 shows the different stages of the evolution of bicycles. It shows the intermediate states before reaching the final form. From this figure it is clear that any further fundamental change in
the design has not been possible.

Powering the Bicycle and Emergence of Automobiles

A point needs to be emphasized here that wheeled vehicles existed from antiquity. But in all cases, such vehicles were pulled by animals like horses, bullocks, etc. Bicycle is the first example of a vehicle not being pulled by any animal. Of course, the source of motion is the muscle power of the rider. The idea of such a vehicle for more passengers was soon to follow quite naturally, and the first step towards that was the development of tricycles. It became a fashion among the well to do families to go to social functions in tricycles. Figure 11a shows a modified tricycle in which the famous author Sir Conan Doyle and his wife are the

Bicycle is the first example of a vehicle not being pulled by any animal. Of course, the source of motion is the muscle power of the rider.
Figure 11. Tricycle as a mode of transport for aristocratic families.

The dynamics of a bicycle belongs to a particular class called the 'dynamics of non-holonomic systems'.

Steam engines were already running all over the world, and attempts were made to power bicycles with steam engines as shown in Figures 12. But as can be easily understood, such forerunners of today’s motorcycles were extremely clumsy and potentially dangerous. Soon came the internal combustion engines and early motorcycles emerged as shown in Figure 13. A tricycle fitted with an IC engine is also shown in the figure that ultimately led to the development of automobiles. This has been shown in Figure 14.

Dynamics of Bicycle Motion

The dynamics of a bicycle belongs to a particular class called the 'dynamics of non-holonomic systems'. In this article, an extremely simplified analysis is presented that helps to understand some of the basic experiences of a rider. To begin with, it is de-
sirable to be familiar with the important dimensions of a bicycle. The major dimensions are the distance between the front and rear wheels and the location of the combined centre of mass of the cycle and the rider(s). Figure 15 shows two views of a bicycle with a rider moving with a velocity \( v \). The front and the rear wheel centres are at a distance \( l \) apart. The horizontal distance of the combined centre of mass \( G \) from the rear wheel centre is \( x \) as shown in the figure. Whenever there is a tendency to fall due to the gravitational pull on \( G \), the rider turns the handlebar in the direction of the falling tendency with an angular velocity \( \omega \) as indicated in the figure. It has to be remembered that all these are
Figure 14. Emergence of automobiles.

of very small magnitudes (i.e., the tilt of the bicycle and the angular velocity of the handlebar along with the front wheel plane). It is shown below that due to the angular velocity, \( \omega \), the centre of mass \( G \) gets accelerated in the inward direction. The magnitude of the acceleration of the centre of mass \( G \) can be found out when the handlebar (i.e. the front wheel plane) is given an angular velocity \( \omega \) as shown in Figure 16. When the front wheel plane is inclined by a small angle, \( \theta \), the entire bicycle starts to rotate about the common centre \( O \), given by the intersection of the front and the rear wheel axes as shown, the instantaneous velocity of the centre of mass being \( v_G \) as shown. The direction of the velocity vector is perpendicular to the line \( GO \). When the front wheel plane is given a small rotation \( d\theta \) in a time interval \( dt \), the centre of rotation changes to point \( O' \) as shown in Figure 16b. This causes the velocity of the centre of mass \( G \) to change direction, keeping it perpendicular to the line \( GO' \). The change in the velocity vector \( v_G \) can be expressed as follows:

\[
dv_G = u_f dv_G + u_t v_G d\varphi.
\]

Here \( dv_G \) is the change in the magnitude of the velocity. \( u_f \) and \( u_t \) are unit vectors in the forward and transverse directions as shown.
in Figure 16a. If the speed of the bicycle remains unchanged then 
\(dv_G\) is zero and

\[dv_G \approx u_t v_G d\varphi.\]

Thus, the generated acceleration of the centre of mass in the transverse direction is given by

\[a_G = \frac{dv_G}{dt} \approx u_t v_G \frac{d\varphi}{dt} = u_t v_G \frac{d\varphi}{d\theta} \omega,\]

since \(\omega = d\theta/dt\). As \(\theta\) and \(\varphi\) both are very small, from the figure one can write

\[\theta \approx l/OB \quad \text{and} \quad \varphi \approx x/OB,\]

or,

\[\frac{d\varphi}{d\theta} = \frac{x}{l} \quad \text{(a constant)}.\]

Hence \(a_G \approx u_t v_G \omega (x/l)\).

Applying d’Alembert’s principle, it can be shown that this acceleration will develop an inertia force \(ma_G\) in the opposite direction, acting at point \(G\) as shown in Figure 15, balancing the falling moment and stabilizing the bicycle. \(m\) is the combined
mass of the rider(s) and the bicycle. Learning cycling is nothing but developing the skill of manoeuvring the handlebar continuously in an almost imperceptible manner to generate this inertia force as required. The result of this simple analysis matches the real experience. As a large $a_G$ helps to counter the moment due to weight $mg$, the conditions that lead to this are larger speed $v_G$, larger $\omega$, and larger $(x/l)$. Hence small manipulative $\omega$ can balance if the speed is large. Similarly, having a co-passenger in the carrier shifts the centre of mass, reducing $x/l$ requiring larger $\omega$.

These all match with the common experience. A more detailed analysis is beyond the scope of this article, as mentioned earlier.

**Contribution to Social Reform and Women’s Liberation**

Though not often recognized, bicycles brought in drastic social changes, particularly in the lives of women. Although initially, bicycles were only available to well to do families and aristocrats, soon its price came down to a level when a common person could own one. This personalized transport facility brought a number of changes for the working class. It also gave the workforce in the industry and other organized sectors the facility to organize meetings and group discussions. In a sense, it helped the socialistic movements.

But the real impact was in the lives of the women. The most remarkable achievement of the bicycle revolution was liberating women from the domestic confines. It not only brought a change in their lifestyle but also resulted in major changes in the dress code to the utter dislike of the male community. The women could easily meet in groups and many cycling groups came up as indicated in Figure 17.

As can be seen in the picture, the dress of women cyclists was still conservative and was not very conducive for free movement of the legs. Thus, gradually a tendency developed to bifurcate the lower part of the dress, as shown in Figure 18, to the utter dislike of the male community. This type of dress was called ‘the rational dress’. With this new type of dress, women riders were free
from their restraining corsets and heavy undergarments. The total weight of the ladies’ undergarments came down to seven pounds. But the male community were against the idea, and a vicious campaign was started against women bicyclists. The doctors cautioned that the seating posture poses serious health problems for the ladies. They invented another imaginary symptom—the ‘bicycle face’. According to this, constant attention for maintaining balance caused the face to develop a stern look losing its femininity, and making the cycling women ugly looking. It was later found to be totally baseless suspicion. Besides, many doctors cautioned female bicyclists of developing serious gynaecological problems.

This new dress of the female cyclists was so much disliked by the male community that often such female cyclists used to get mobbed in the streets of the towns and cities. Figure 19 shows a case reported in 1897 newspapers of Paris in which a female bicyclist in ‘rational dress’ was mobbed, and she had to escape through a restaurant using the back door!

Figure 20 shows how the dress for the female cyclists gradually changed. First, the skirt was cut in the middle to allow free movement of the legs. Then the ‘rational dress’ was conceived. What the gentlemen did not like was the visibility of women’s legs and the fact that the dress resembled that for gentlemen.

There used to be many cartoons depicting women cyclists, and
Figure 17. A typical women bicycling group of late 19th century Europe.

Figure 18. The rational dress.

the dangers they pose to society; Figure 21 is a typical example. There also used to be frequent letters to the editor in newspapers,
expressing the disgust the male community harboured towards female bicyclists. *Figure 22* is a typical example of one such letter published in the *Sunday Herald* in 1891. The freedom that bicycles provided, being enjoyed by women, was very much disliked, but not only by the male community. Interestingly, even some female activists were not in favour of women on a bicycle! Charlotte Smith of Women’s Rescue League wrote this in 1896, “Bicycling by young women has helped to swell the ranks of reckless girls who finally drift into the standing army of outcast women in the United States.” Many female cyclists on cigar box labels (*Figure 23*) were shown as decidedly masculine, with hair cut short or pulled back, and smoking cigars, then an almost exclusively male pursuit. This portrayal reflected the old fears that women in pants would somehow supplement men as bread-earners and

*Figure 19*. Female bicyclist being mobbed.

There used to be many cartoons depicting women cyclists, and the dangers they pose to society. There also used to be frequent letters to the editor in newspapers, expressing the disgust the male community harboured towards female bicyclists.
Figure 20. Gradual change in the dress code for women.

Figure 21. Cartoons depicting the dangers of allowing female bicyclists.

decision-makers.
Not only the common public, even those in academia were not far behind in bashing women on bicycles. The undergraduate students of Cambridge demonstrated in 1897 against the award of degrees to female students, and they burnt an effigy of a woman on a bicycle!
It may sound strange today, but till the 19th century in England, female students were not given degrees by the universities! It was also thought that women were incapable of handling analytical and mathematical problems. In 1890, Ms Phillippa Fawcet proved them wrong by far surpassing all students in mathematics at Cambridge University. This stunned all, but being a girl student, she did not get a graduation degree. Commenting on the demand that the girl students be given degrees by the university, a prominent intellectual of that time, Mr J. P. Thompson, said, “If I give a beggar my coat he has no right to ask for my trousers too.” In 1897, two women’s colleges—Griton and Newnham—in Cambridge proposed to the University that the girl students be given degrees. The University called a Senate meeting to discuss this agenda, but there was a tremendous protest demonstration by male students against the proposal. Male students felt threatened by the girl students’ rise to equality! As a woman cyclist was the symbol of women’s empowerment, they burnt an effigy of a girl bicyclist during the demonstration as seen in Figure 24. After the failed attempt by the University to award degrees to female students, another attempt was made in 1921. But, unfortunately, that also failed! At last, in 1947, a third attempt was made, and it succeeded! The first-ever female degree recipient of Cambridge University was Queen Mother Elizabeth II; she received the degree in 1948!

The transformation indicated symbolically in Figure 25 took more than a century before women could finally come out of the shackles of social taboos. Figure 26 shows symbolically the overall contributions of bicycles in the development of technology and their role in social transformation.

Bicycles brought another important but often less noticed change
Figure 23. A cigar box label in late 19th century United States.

Figure 24. Male student community protesting against girls being given degrees by Cambridge university during the senate meeting in 1897.

In society, it brought an increased level of health awareness since bicycling became a major sport. Many special versions of bicycles have been developed primarily for use in sports and similar outdoor activities. Since the costume for such bicycle usage became more modern (and also bolder for the women), it further enhanced the sense of liberty among the women, as can be seen in Figure 26. In present-day India, various programmes have been started by the government to distribute bicycles among the girls of rural areas to provide them with better mobility and more freedom. Thus the image of the bicycle as a harbinger of freedom and mobility persists.
Concluding Remarks

Thus, the above discussion clearly shows the colourful history of bicycles and their impact on surface transportation. Apart from being the motivating agent for many technological innovations, it gave birth to the concept of automobiles. On the other hand, this inexpensive personalized transportation brought many revo-
volutionary social changes, particularly in the lives of women. It is so familiar a companion in our daily lives today that it hardly gets the attention and appreciation it rightfully deserves.

Suggested Reading