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Analysing Technology.

Of Bicycles, Drones and Virtual Reality.

Bachelor-Thesis

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Matriculation Number: 1784

New Media

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Winter semester 2019/2020

Contents

Introduction

The outcome of the evolution of technology is easy to grasp in retrospect: The development of virtual reality gave birth to a whole palette of new possibilities on a wide range of applications, the bicycle changed the way of civil transportation, developing drones contributed to the evolution of modern warfare and eventually to photography. But what do these and many more technologies have in common?

The following chapters will investigate similarities by looking at the history of each of them. We will look at how technology affects its users and vice versa. The knowledge that Science and Technology studies provide will help us analyse important milestones in the history of the bicycle. Looking at the producers and users of drones will help us determine the current state of the drone. After having developed both models, we will apply them to the evolution of virtual reality.

The purpose of this work is to give a brief example of how technologies can be analysed to explain certain trends or events, or the current state the technology is in. The pre-history of anything, can sometimes, reveal interesting facts. When brought into context, those facts can explain future developments, to an extent. The particular character of an industry, that revolved around a technology, can give important insights. The look at important factors, when establishing a market around a technology, will also be covered.

The first two chapters will cover the conceptual definitions needed, with a strong example for each chapter. Let’s start our studies by looking at Science and Technology Studies.

Science and Technology Studies

Science and technology studies (abbreviated further as STS) investigates how technologies develop over time and how we seek to regulate them. One of the main objectives is to seek out how society, politics and culture influence scientific knowledge. In STS technology, society and science can not exist without one another. The social context is influencing the content of scientific thought and vice versa. Nowadays a lot of politics is about scientific matters and a lot of scientific matters inherently have a lot of politics caught up in them. STS is sitting exactly at the point of intersection of these topics. The idea of STS is relatively new and is taught as an academic field worldwide:

> *"Science and Technology Studies (STS) is a relatively new academic field. Its roots lie in the interwar period and continue into the start of the Cold War, when historians and sociologists of science, and scientists themselves, became interested in the relationship between scientific knowledge, technological systems, and society. The best-known product of this interest was Thomas Kuhn's […] study, The Structure of Scientific Revolutions. This influential work helped crystallize a new approach to historical and social studies of science, in which scientific facts were seen as products of scientists' socially conditioned investigations rather than as objective representations of nature. Among the many ramifications of Kuhn's work was a systematic effort by social scientists to probe how scientific discovery and its technological applications link up with other social developments, in law, politics, public policy, ethics, and culture."*[1]

STS is targeting the history of technology, and therefore its philosophy and social groups that revolve around it. There is no critical progress in technology or science without the influence or involvement of important groups. If, for any reason, a technology isn't appealing to certain involved group, its development will be halted, at some point of the STS Cycle (**Figure 1**). The circle can start from any point. Social values lead to scientific research, which will lead to solutions of problems and, therefore innovation. This new feature or technology is then valued by involved social groups, which restarts the cycle. A good example of this is the use of wind power throughout the history. It was used to accelerate ships, to power machines, to grind grain or to pump water. In 1887 physicist James Blyth constructed the first windmill to create electrical power. His design featured a windmill attached to a dynamo. He used his invention to light his cottage in Marykirk.[2] Up until 1973 wind power was widely spread but not as commonly used as today. The oil crisis forced the US government to look for renewable energy

[1] http://sts.hks.harvard.edu/about/whatissts.html. The reference within the quotation is to Kuhn (1962).
[2] https://blogs.bl.uk/science/2017/08/james-blyth-and-the-worlds-first-wind-powered-generator.html

sources and federal funding grew. Through taxing and subsidizing wind energy soon became the cheapest alternative to coal power.[3] From this we can conclude that the US politics forced a rapid development and deployment of this technology. Back when Blyth made his invention there wasn't any taxing or funding in favour of wind-powered electricity. By the time he came up with his invention there was no real value to it, which interrupted the STS Cycle, as the technology wasn't promising enough for people to adopt. It halted its further development up until 1973, when oil prices sky-rocketed. Phenomena like these is what STS is trying to examine in order to develop insights on how technology, science and cultural evolution are directly affecting each other.

To help understand how STS is proceeding in investigating technologies we will now be discussing an example by Wiebe E. Bijker as introduced in his book "Of Bicycles, Bakelites, and Bulbs – Toward a theory of Sociotechnical Change"[4]. The author is investigating the development of the 'safety bicycle', starting from the earliest attempts of humanly-propelled machines to the final stabilization of the modern bicycle.[5] The conclusions drawn in this paragraph will help us to further analyse other technologies. The discussion will include conceptual theories as well as historical facts.

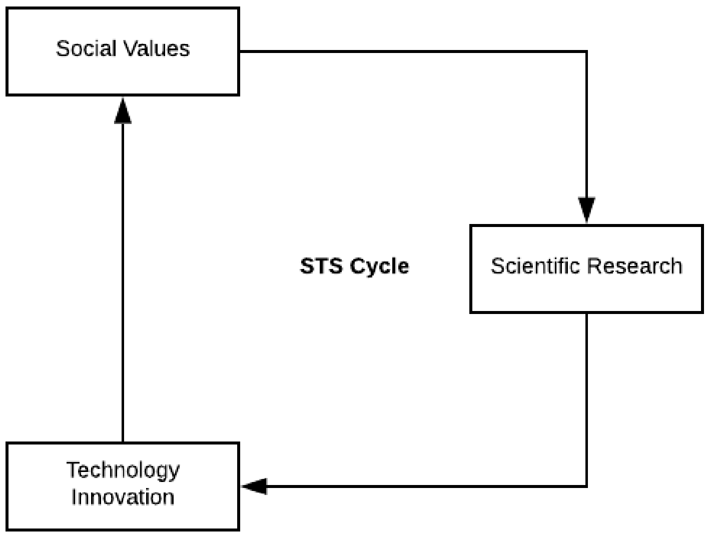

Figure 1
The 'STS Cycle': Social values or needs promote what will be researched. Those results will then be engineered or developed into a technology which will then again be valued by society.

[3] http://www.thirdplanetwind.com/energy/history.aspx
[4] Bijker (1995).
[5] Bijker (1995) 20-100.

The bicycle

The bicycle, as we know it, came a long way. Some sources claim that Leonardo Da Vinci was the first to sketch the design of a stable two-wheeled vehicle in 1493.[6] It is said that his sketch was found in the discovery of the "Codex Atlanticus"[7]. This theory has been debunked in 1997, as German laser scientist Hans-Erhard Lessing proved that Da Vinci never sketched the bicycle.[8] "[…] research showed that two inks on the page said to contain the Leonardo bicycle design dated from post-1880 and post-1920."[9] The first bicycle that solved many problems of earlier models was designed and built by Karl Friedrich Christian Ludwig, Freiherr Drais von Sauerbronn in Mannheim.[10]

> *"In 1817 […] 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. In front of the saddle was a cushioned bar on which the underarms could be rested. […] 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. […] 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 stagecouch."*[11]

Some features of his design can even be seen in modern bicycles. Two wheels of equal size, a cushioned saddle, a cross-frame connecting the wheels. Demonstrating the speed of his invention lead to positive press comments at first. But his "Draisienne" soon became the target of caricaturists, pedestrians, and schoolboys, because of its unreliability and the wear on the rider's shoes.[12] It is interesting to state that the eruption of Mt Tembora in Indonesia led to a climate catastrophe in Europe with horses dying in 1816 and 1817, and therefore the need for a horse-substitute emerged.[13] This led to a craze of new prototypes in other countries, but notably in England, were the Draisienne had more success. Commonly known as the hobbyhorse or "dandyhorse", Denis Johnson developed a model for postmen in 1819 and for women in 1820. Several "riding schools" were established in England, and even in America. The new sport soon seemed to anger the public, perhaps because riders were using footpaths, speeding downhill without brakes or because there was no place to rest your feet, resulting in messy shoes when

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[6] Bijker (1995) 20.
[7] Da Vinci (1780).
[8] https://www.bikebiz.com/laser-scientist-who-proved-that-leonardo-da-vinci-didnt-invent-the-bicycle-turns-80/
[9] https://www.bikebiz.com/laser-scientist-who-proved-that-leonardo-da-vinci-didnt-invent-the-bicycle-turns-80/
[10] Bijker (1995) 21.
[11] Bijker (1995) 22.
[12] Bijker (1995) 24.
[13] https://www.bikebiz.com/laser-scientist-who-proved-that-leonardo-da-vinci-didnt-invent-the-bicycle-turns-80/

driving through the mud. Perhaps the biggest drawback was the absence of comfort. Wooden or iron-clad wheels, a rigid frame, and countless potholed roads resulted in a rough ride.

Having captured the main problems of early bicycles we will now fast-forward to how those problems have been countered and which social groups were involved in the development of the ‘Ordinary bicycle’.

The ordinary

Inventors came up with methods to raise the feet off the ground. By using cranks on the rear wheel, the problem was solved rather easily in 1839.[14] To provide a more comfortable ride the size of the front wheel was slowly increased, which resulted in less vibration. In 1870 J. Starley patented the the “Ariel”, which is generally considered to be the first high-wheeled “Ordinary bicycle” (**Figure 2**).[15]It had solid forks, plain bearings and a roller brake on the rear wheel. Later it came with adjustable spokes, which led to not having to bend them anymore to stiffen them.[16]

Figure 2
The “Ariel” was patented in 1870 by J. Starley and W. Hillman. It is considered the first high-wheeled “Ordinary bicycle”. It is fitted with a lever that rotates the hub.

[14] Bijker (1995) 24 -25.
[15] Bijker (1995) 31.
[16] http://the-ariel.british-ordinary-bicycles.ordinary-bicycles.antique-bicycles.net/

Social groups

On July 19th, 1870 French emperor Napoleon III declared war on Prussia to restore his declining popularity in France. French generals were blinded by national pride and were overconfident of victory. After losses in the Battle of Wörth and the disastrous Battle of Sedan, the French army surrendered on the September 2 after losing nearly 17.000 men in battle.[17] This war had a destabilizing effect on the British industry. Export opportunities grew scarce and forced many machine and weapon manufacturers to shift their production.[18]

In this section we will further investigate what various social groups are involved in production and which effect the Franco-German War had on establishing the mass-production of bicycles in England in the late 18th century. Let us first examine the social group of producers.

The Producers

Up until the 1860s only carriage builders were able to build velocipedes (humanly-propelled vehicles with one or more wheels). In the 1870s the areas around Leicester, Liverpool, Birmingham, and especially Coventry saw a dramatic increase of workshops where velocipedes are manufactured, as production lines shifted due to a weakened industry. Coventry soon became the velocipede-manufacturing hot-spot in England.[19]

> *"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. […] 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"*[20]

Starley and Hillman wanted their high-wheeled bicycle Ariel to be marked with a spectacular launch. Displaying its speed seemed like a fitting promotional feat. "They decided to set up a kind of unusual test: completing the ride from London to Coventry in one day. […] On some steeper hills they had to walk, but compensation came on the long downhill portions where speeds of some of twelve miles an hour were attained."[21] With minor incidents the 96 miles long tour was completed within one day. Although the riders had to remain in their beds for two to three days, it was still a huge success in promoting their high-wheeled bicycle.

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[17] https://www.britannica.com/event/Franco-German-War
[18] Bijker (1995) 32.
[19] Bijker (1995) 32.
[20] Bijker (1995) 35.
[21] Bijker (1995) 36.

Having looked at how the producers have established a highly functional network of suppliers in England, and how they tried to sell and promote their products (mainly through showcasing its speed and high comfort), we will now look at whom they were producing them for.

The Users

The ride of the Ariel further improved the image of high-wheeled bicycles as sport machines. Frequent rides on Brighton Road were held, where bicycles would often win against four-horse coaches. Track racing started in London, Birmingham and Wolverhampton.[22] Cycling required a rather athletic physique, as it wasn't easy to mount a high-wheeler. "Going head-over-heals was quite common. […] Even walking a bicycle could result in a bruised leg when the novice hat not yet learned how to keep free of the revolving pedals."[23] Despite from the required physique bicycling also still had an element of showing off. It can be compared with showing off an expensive, fast or extraordinary car nowadays. Bicycling was associated with progress and modern times; therefore, middle-aged men were the main target-group of producers. The working class could not afford high-wheeled bicycles, until a second-hand market developed. "[…] 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."[24]

In conclusion, the social group of users consisted of young, athletic men, who were able to afford a high-wheeler. On the contrary there were still many "non-users" of the ordinary bicycle at that time. Pedestrians who experienced incidents with ruthless cyclists, people who could not afford a bicycle or who weren't athletic enough to drive one.

The Non-users

While many simply could not afford or mount an ordinary bicycle, there were also others who actively opposed the machine by various reasons: Pedestrians having to wait before crossing the street, carriage drivers being overtaken, newspaper reports about fights between bicyclists and pedestrians, just to name a few. Cyclists were constantly insulted and shouted at by the non-users, resulting in aggression and even attacks against cyclists by throwing objects between the spokes of the wheels.

But not every non-user was opposing the machine. The price of ordinary bicycles prevented middle-class and working-class people from buying a new machine. Older men could not ride a high wheeler because of safety reasons. For most people, the "safety problem" was

[22] Bijker (1995) 37.
[23] Bijker (1995) 38.
[24] Bijker (1995) 41.

still very present. Once speed became so important, the reaction of the producers was to reduce the rear wheels diameter and increase the front wheels size. This resulted in other safety problems, as the drivers position now was almost above the turning point of the system. Bumpy roads or sudden breaking would topple the bicycle.[25]

Now that we are aware of social groups, and discussed some of their individual problems, let's look at how these problems are solved.

Trial and Error

To gather information about a topic, one does not look at it in a well-balanced and steady state. Children learn through using things the way they're not supposed to be used. Focusing on interruptions, rather than looking at its working state, can be useful when investigating the meanings of an artefact, in our case the bicycle:

> *"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, (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."*[26]

According to Bijker problems are solved in an evolutionary process of variation and selection of solutions. Chosen solutions will then lead to new artifacts and innovation. Being stuck on either of the points mentioned by Bijker, will halt the development of given technology.[27]

The Tricycle

To counter the instability of the bicycle one logic step was to add another wheel to it. Even though tricycles had existed before the safety problem of the bicycle, they never reached commercial viability. After the bicycle created a market for humanly-propelled vehicles the tricycle was reinvented, to generate profit on the safety problem. Tricycles soon became popular among lady cyclists, countering the problem of inadequate clothing, as they weren't forced to wear special outfits to drive one. But other problems emerged. Turning a tricycle often lead to swerving, as one wheel was spinning faster than the other. To counter this new problem, the differential gear was invented, making the tricycle appeal to a wide variety of users. The tricycle

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[25] Bijker (1995) 42-43.
[26] Bijker (1995) 51.
[27] Bijker (1995) 52-53.

soon became fashionable among the elite, as it targeted women and elderly men, involving a new social group into the development of self-propelled vehicles. Manufacturers started producing tricycles parallel to bicycles in the 1880s. Back then it slowly seemed the tricycle will, sooner or later, replace the bicycle completely. Bicycle producers became aware of the potential of a new growing market for sales, if they could solve the safety problem of bicycles.[28]

The tricycle was advertised as safe and suited for the elderly but came with safety problems of its own. Where the bicycle only had one track, the tricycle had three. This made it significantly harder for the cyclist to avoid stones and holes on the roads. In addition, there were no brakes on tricycles making it crucial to not let your feet slip off the pedals, when going downhill. Many tricyclists were lifted from their seats in an attempt to regain control over the fast spinning pedals. Soon tricycles accidents outnumber those with bicycles.[29] These machines posed problems of their own. Their lack of success left room for alternative solutions.

Safety bicycles

Since tricycles proved to have their own problems, most producers switched back to solve the problem by modifying the basic scheme of the ordinary bicycle. By moving the saddle back, the safety problem was reduced, but vibrations increased as the rider's weight was above the rear wheel. To cope this problem, the rear wheel was enlarged. In addition to reducing vibrations the rider's position now was between the wheels, rather than above one, which further stabilized the vehicle. Moving the saddle back came with another problem: Treading the pedals became less comfortable, as the rider was now behind the pedals, and not directly above them as before. Extending the pedals backward by some lever mechanism solved the problem:[30]

> *"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."*[31]

Since decreasing the size of the front wheel to increase the safety of the bicycle lead to lower speeds compared to high-wheeled bicycles, new acceleration mechanisms were needed. Adding a chain drive with a ration which compensated for the smaller wheel radius solved the problem

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[28] Bijker (1995) 54-59.
[29] Bijker (1995) 59-60.
[30] Bijker (1995) 60-61.
[31] Bijker (1995) 61.

in 1877.[32] The safety problem was far from solved by that time. One radical way to solve it was by reversing the order of the big and small wheels. Now the rider sits on the rear wheel. A complex lever-type system had to be implemented to bring the pedals forward to the feet, which ended up in a rather mixed commercial success in the United States.[33] When the first rear-driven low-wheelers came up they proved themselves, as it often was with bicycles, on the race track:

> *"[…] the rear-driving type of safety has been found to be so speedy, as well as safe from liability to headers, that it has almost monopolized the public taste, successive improvements having resulted in the manufacture and use of this type far exceeding that of the "ordinary" or tall bicycle"*[34]

The invention of the first safety bicycle is regarded as one of the most important moments in the history of humanly-propelled bicycles. "[…] bicycle design and equipment became standardized across the world and they satisfied all four basic aspects – safety, speed, comfort and steering. They all had the basic diamond shape made from metal, pneumatic rubber tires, roller chain, one gear, coaster brakes and more."[35] Bicycles became the primary means of public road transportation in the years from 1900 to the 1950s. Manufacturing costs came down significantly, which spread the use of bicycles all over the world, stabilizing its position.[36]

Cutting the historical part here, we will now discuss the theory behind it. As I already stated there were low-wheeled bicycles prior to the high-wheeled ordinaries. How can we then understand the role of the detour to the high-wheeled bicycles in relation to its low-wheeled successors and ancestors?

Forming the model

Features which are used in modern bicycles were already available before the high-wheeler. These ancestors weren't as appealing as the high-wheelers, which brought new features but again, new problems with them. The lack of speed or safety was more like a feature of the high-wheeled bicycles. Being driven by young, athletic and wealthy men, who liked to show off their physique and wealth, the high-wheeler was more of a lifestyle gadget than a transportation vehicle. Since the safety problem could not be solved with minor improvements the producers reordered the classic scheme of high-wheeled bicycles. This led to significant improvements on stability, comfort and safety. Elderly men, women and the elite are starting to be attracted to

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[32] Bijker (1995) 63-64.
[33] Bijker (1995) 66-68.
[34] Ritchie (2018) 169.
[35] http://www.bicyclehistory.net/bicycle-history/history-of-bicycle/
[36] http://www.bicyclehistory.net/bicycle-history/history-of-bicycle/

those new forms of velocipedes. Tricycles solved the safety problem but came with yet other problems, which required inventions. Those inventions were then used to reassembly the safety bicycle. Testing the safety bicycle on race tracks then sealed its fate, as it was crushing its high-wheeled opponents.

All these artefacts and events are crucial in stabilizing the safety bicycle. Focusing on relevant social groups and their problems made us look at their solutions and vice versa. From our studies we can extract a model[37] **(Figure 3)**, where the evolution of the bicycle can be displayed. From prehistory we've learned about the existence of low-wheeled velocipedes way before the safety bicycles. When the first high-wheeler appeared, a new market was established, with involved social groups. Solving problems is accomplished through trial and error and through reordering classic schemes, like adding a third wheel to a bicycle to counter the safety problem. Those radical changes led to new problems, which are countered individually. This leads to the disappearance of problems. These inventions are then added to the safety bicycle to finally stabilize its position.

Having established this model, which we will follow to investigate other technologies, it is time to move on to the next essential step by looking at the principle of "critical mass" in technology adoption.

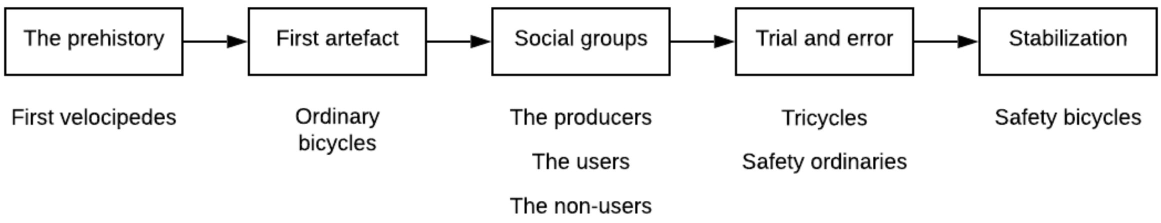

Figure 3
A model to investigate the evolution of technologies.

[37] Bijker mentions 'interpretative flexibility' in his analysis of the evolution of the bicycle. The bicycle was difficult to mount and dangerous to ride for both pedestrians and the cyclists. For others it was more of a tool to showcase wealth and an athletic physique. Looking at technology from different perspectives is important in its analysis. In this model the interpretative flexibility is implemented in all the steps and does not need to have an explicit chapter on its own.

Technology adoption

In nuclear physics, critical mass is the minimum amount needed for a fissile material to achieve a self-sustained fission chain reaction.[38] To sum it up, we need a given number of molecules of, for example, water to form a drop. In a gas the molecules are too far apart for it to form a drop. In a transferred sense, it means that for a technology, there is the need of a certain number of users and vendors in a specific density to make it grow. Increases in density form around explicit foci. “When these foci start to emerge, users and vendors start to be attracted towards these ‘leading designs’ and this builds up a critical mass of activity around each focus.”[39]
It is fundamental for a technology to increase the density of users and vendors in these individual foci. Swann and Watts explain the importance of the paradigm for the growth of a market in four simplified steps:

> **“*A common language is essential for the growth of trade.***
>
> *This first point may seem obvious, but it is often taken for granted. The growth of trade from the earliest times required some commonality of understanding between trading partners, some shared language, and also some common weights and measures.”* [40]

In short, we can observe that a common language, with precise definitions, which does not consist of several different jargons, is required to attract buyers. Otherwise buyers could be confused and won’t understand the advantage of what is being offered.

> **“*A common language emerges around a paradigm.***
>
> *[…] Why do languages diverge? […] divergence is a natural and, to some degree, random process of entropy. Arguably it may also be deliberate: divergences in languages or dialects create barriers to competition. […] In normal science, the paradigm is accompanied by communication between researchers. No longer ‘sole traders’, they build up a common model by sharing results and findings. That communication requires a common language, but not necessarily a new one.”* [41]

Through travelling, trading and communicating languages can diverge or converge. Therefore, a common language emerges if, for example, researches are investigating the same paradigm, and it recedes if dialects or jargons are introduced.

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[38] https://www.britannica.com/science/critical-mass
[39] Swann / Watts (2009) 44.
[40] Swann / Watts (2009) 46.
[41] Swann / Watts (2009) 47.

> **"*The risk-averse buyer faced with undue complexity does not buy.***
>
> *One of the most telling critiques of modern economic consumer theory is that many practical choice problems are simply too complex for the consumer to be able to optimize in the way that consumer theory assumes. […] Accordingly, the buyer must use simple rules of thumb: for example, to buy a particular brand, or to repeat previous purchases. When it comes to making selections in the area of new technologies, however, such simple rules are unlikely to help."*[42]

If a technology is too complex for the average buyer to interpret, he might not make a purchase at all. That can be traced back to the lack of a common language. If good communication and a relatively riskless entry point are established buyers are much more likely to make the first step towards an emerging technology.

The last step is about reliability of a new technology. Buyers might not be able to survey all its progress which, once again, shows the importance of a paradigm. G. M. Peter Swann and Tim P. Watts show this with a fitting example:

> **"*New technologies tend towards unsurveyability without a paradigm.***
>
> *[…] imagine that we use a tree diagram to map different developments in a technology. Suppose that each final node represents a new and distinctive version of the technology or method of application. Imagine also that innovation is continuing, so that each final node of the tree diagram splits into two further branches in every period of time. In that case, by the end of period t a total of 2^t nodes will have appeared. As t increases, this rapidly becomes unmanageable."*[43]

This example might be hard to grasp at first, but it displays what innovation does to a technology. Without the presence of a paradigm buyers are unsure about the complexity and the field becomes less transparent. When new features are introduced and naming conventions are unclear, buyers are much less likely to invest, even though it might be a revolutionizing technology.

To sum it up the paradigm is playing two essential roles when it comes to growing a market. The emergence of a common language which is essential for trading. And the ability to have a level of complexity, which the buyer is still able to grasp. But how does one increase the density of producers and buyers, to eventually form a critical mass with a leading design?

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[42] Swann / Watts (2009) 47.
[43] Swann / Watts (2009) 48.

Increase density

Superior infrastructure, a superior labour market, and the ability to network with related companies is the ideal case for growing a dense customer base. However, it comes with consequences, such as higher costs of labour and real estate and a greater competition. By contracting out 'non-core' activities to third parties a company can survive this competition on the long run. Specializing in areas where competencies are given further stabilizes the position of a company. This leads to a network where one company's activity depends on the activities of others. In theory, the innovator could profit of just connecting two specialized companies to form a new product. No competencies needed. The difficulty lies in communicating between these companies as they were formerly unconnected. The innovator is required to have command of both paradigms and their associated languages. When a technological branch becomes densely populated, the competitive pressures lead to increased specialism. Trying to produce everything inhouse and supplying complete solutions, will only yield moderate results. Instead companies should focus to specialize components or services, to stay relevant.[44] In order to outsource specific tasks, common terms for items or services must be established, therefore the need for a paradigm emerges.

Swann and Watts try to explain the ideal growth of a market by dividing it up into two phases: The pre-paradigmatic and the diffusion phase. By comparing them we can clearly tell those phases apart.

The pre-paradigmatic state

In the pre-paradigmatic phase, uncertainty and the lack of consensus about vision is present, preventing the technology to show its full potential. Since there is no network of companies and services yet, the selling costs are too high. Having a wide range of application for the technology leads to confusion among customers, unless it is the 'killer application'. The generally high risk to buy a new product without standardized components or services, leads to buyers not investing much.

Diffusion

The diffusion phase starts when the paradigm has emerged, and a common language has been developed. Standardized commands and components are now established and used to outsource certain tasks to other companies, which results in declining selling costs. Expectations of users and vendors are in line and communication is much clearer. Since the technology can now be

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[44] Swann / Watts (2009) 49-50.

surveyed, paradoxically, a wide potential of application becomes helpful. Even though technology may still evolve in this state, costumers now have something concrete to work with.[45]

The ready-to-fly drone

Has the drone, as we know it, left the pre-paradigmatic state to enter the diffusion state? To answer this question we must, once again, look at history. We shall investigate if a common language has emerged around it. We then study its vendors and users over time, to check if diffusion already took place or when to expect it. I will only briefly give an overview of how drones have evolved over time, by displaying relevant milestones of its history.

History of drones

In 1907 the worlds first quadcopter was created by Jacques and Louis Breguet. This new formfactor came with some big limitations: It could not be controlled, required up to four men to steady it, and lifted just two feet off the ground in its first flight.[46] It nevertheless provided the quadcopter formfactor we use to this day. Even though, there were other unmanned aerial vehicles before (further abbreviated as UAVs), such as the Austrian balloons, which were used to bomb Venice in 1849[47], I will focus on the winged and quadcopter formfactors.

Shortly after World War I, the first radio controlled, pilotless airplane was built. It was meant to be used as a flying bomb, which could be piloted into the enemy. Even though it was never used in combat, it opened the door for similar projects and paved the way for military drones. The German military created the first remote-controlled weapon nicknamed ‘Fritz X’, that was put into operational use, in 1943. Engineers attached a 2,300-pound bomb to sink ships during combat.[48] Prior to that, in 1936, the term ‘drone’, linked to remotely controlled aircrafts, was established by the US Navy, as they were researching pilotless planes themselves.[49] Those early drones proved to be a failure, because of their unreliability and short range. Nonetheless, the early assault drone played an important role in projects that would re-emerge years later in another, flexible iteration.

The 1960s led to a boom of RC planes in the United States. Breakthroughs in transistor technology allowed building miniaturized radio-controlled components at reasonable costs.

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[45] Swann / Watts (2009) 51.
[46] Dormehl (11.09.2019) https://www.digitaltrends.com/cool-tech/history-of-drones/
[47] O’Donnell (16,06,2019) https://consortiq.com/media-centre/blog/short-history-unmanned-aerial-vehicles-uavs
[48] Dormehl (11.09.2019)
[49] Chandler (2017) 89.

Now private customers could purchase RC planes, which offered everything from small indoor models to large outdoor planes. The cottage industry emerged from people building their RC planes at home, as they mostly came in kits. This can be seen as an early example of the kind of community and market which will emerge for consumers of drones nearly half a century later.[50]

After mainly being used in experimental surveillance until the 1980s, Israel instrumentalized drones for the battlefield. The attitude towards UAVs, which were often seen as unreliable and expensive toys, dramatically changed when the Israeli Air Force crushed the Syrian Air Force in 1982. Israel used UAVs to coordinate attacks alongside manned aircraft, which led to quickly destroying dozens of Syrian aircraft with minimal losses. The 1980s were all about UAVs to support ground troops and air forces. US military operations in Grenada, Lebanon, and Libya identified a need for unmanned, reconnaissance, and battle damage assessment capability for local commanders, resulting in the acquisition of UAV systems for the US Navy forces in 1985. A cooperation between the US and Israel resulted in the production of the RQ2 Pioneer, a medium size reconnaissance drone.[51] Seeing the potential of drones being used in actual combat rather than surveillance, the US deployed the famous 'Predator' drone in 2001 as part of the war against the Taliban in the aftermath of 9/11.[52] Even though the Predator UAVs (**Figure 4**) have been operational in Bosnia in support of NATO, UN and US operations[53], it was after 9/11 and the hunt of Osama Bin Laden, which resulted in killing an innocent man named Daraz Khan, that led to growing concerns about the use of drones in warfare.

[50] Dormehl (11.09.2019)
[51] O'Donnell (16.06.2019)
[52] Dormehl (11.09.2019)
[53] https://www.airforce-technology.com/projects/predator-uav/

Figure 4
The MQ-1 'Predator' operated over 500.000 flight hours around the globe. It is a long endurance, medium altitude unmanned aircraft system for surveillance and reconnaissance.[54]

The private sector really began to take off very recently, in 2006. One of the reasons for this rapid grow was the first official commercial drone permit, issued by the Federal Aviation Administration, that stated that drones were safe to use under proper regulatory measures. Before that, small non-military drones were mainly used in disaster relief, border surveillance and wildfire fighting, while corporations began using drones to inspect pipelines and spray pesticides on farms.[55] In 2010 French company Parrot released their famous Parrot AR Drone, a ready-to-fly drone which can be controlled via Wi-Fi, using a smartphone or tablet device. They sold nearly half a million units, making it a huge success for the company and paving the way for newcomers to pick-up-and-play. Jeff Bezos, CEO of Amazon, proposed using a drone-based delivery system in 2013. Realizing that would require some federal rule changes, which Amazon is fighting for to this day, the project is halted but his vision lives on.

The 2016s DJI Phantom 4 marked the era of smart drones. It introduced machine learning and smart computer vision. This allowed to avoid obstacles or to intelligently track people, animals, or objects. This UAV was a major milestone for drone photography and consumer drones in general.[56]

The status of drones

Having had a brief overview of the evolution of UAVs or drones, we will now investigate whether drones left the pre-paradigmatic phase to enter a diffusion state, and therefore increased its density of users and vendors.

The idea of pilotless aircrafts itself can not really be traced back, as its origins are too diverse. In the early years, before being instrumentalized for military needs, inventors were not connected to each other. Prototypes of drones came from all over the world, resulting in language barriers and even the barrier of war - World War II in this case. As the term 'Drone' or UAV was widely adopted, a common paradigm slowly started to emerge. Radio or television-controlled devices were hard to grasp, but seemed like an opportunity for specialization. The US cooperated with Israel, in the search of experts of this field. This joint project resulted in revealing the full potential of the technology, military-wise, and eventually resulted in concerns about the use of military drones around non-military social groups.

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[54] https://www.airforce-technology.com/projects/predator-uav/
[55] Martinez https://www.dronethusiast.com/history-of-drones/
[56] Dormehl (11.09.2019)

The establishment of the recreational market started with the RC plane craze in the 1960s. Enthusiasts and producers set standardized terms for components, low production costs of transistors saw selling costs of RC planes declining, which further stabilized the market. After being exposed to private use in 2006, drone's availability skyrocketed. The term 'drone' became widely known as a device for photography or fun, getting rid of its military ancestors. The area of application is clearly visible to vendors and users, while still offering huge potential in other fields, like transportation or delivery. Countless companies manufacture modular, standardized drone systems, establishing networks of specialization and service.

Drones have come a long way from the early days of confusing radio-controlled unmanned vessels, to the easy-to-use quadcopters for recreational use. The military use continues, but it is the private sector were the technology saw the biggest growth among users. Drones clearly left the pre-paradigmatic state, since standards have emerged, networks have been formed, and prices declined. The growth of drones became exponential when it reached full diffusion in 2006, even though it hasn't reached its full potential yet, and leaves space for innovation to come.

From studying this topic we can, once again, form a scheme or model to apply to other technologies as well.

Forming a scheme

As mentioned, for a technology to grow, we need a certain number of users and vendors in a specific density. A simple graph (**Figure 5**) will help in differentiating the pre-paradigmatic phase from the diffusion state. This is not a chronological procedure, even though some items in the graph need the existence of certain other items.

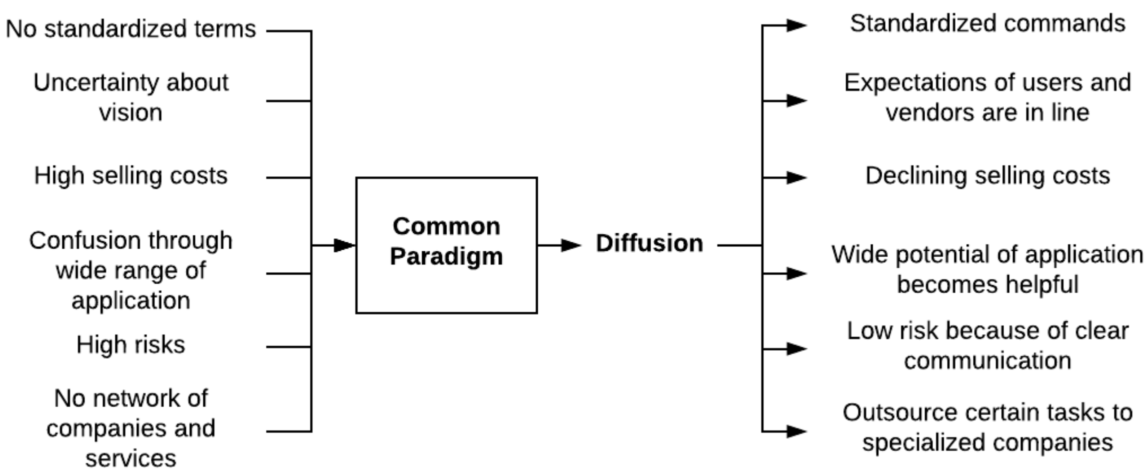

Figure 5
A scheme showing the importance of forming or finding a common paradigm. This shows the ideal case, which is unlikely to be precisely met in reality.

I already briefly explained how to form or find a common language to standardize commands and terms. Users and vendors will be equally sceptical about a technology if its vision is unclear or badly phrased. This disbelief will result in high production costs, since outsourcing of certain tasks isn’t established yet, and therefore high selling costs for the user arise. A technology must be certain in its intended use. In an early state, a wide range of application can be confusing and can not be surveyed by vendors. As a result, investors are deterred to support the technology. Establishing a network to similar companies or services is quite crucial in forming a common paradigm, and further outsource tasks of formerly in-house solutions.

Having left the pre-paradigmatic phase and properly established a network of users and vendors diffusion will take place. Having formed a proper vision, expectations of users and vendors are in line. Having outsourced certain tasks results in much lower production costs and eventually mass-production, which results in declining costs for the user. After standardizing terms and components, a wide range of application, paradoxically, becomes helpful. Clear communication between vendors, investors and users lowers the risk of ‘buying the pig in a poke’.

Analysing Virtual Reality

Virtual reality has recently seen big acceptance by users and developers. Being a fascinating topic, we will apply the models that haven been developed in the last two chapters, to analyse its history and further capture the state it is in today. To do so, we must briefly look at its history to find key events, were development was slowed down or sped up. Focusing on these events, there will be theoretical detours throughout this chapter. We will, once again, focus on relevant milestones in the history of virtual reality (further abbreviated as VR), as fully covering its past would go beyond scope.

History of virtual reality

The idea of head-mounted displays (further abbreviated as HMDs) has been around longer than one might think. The first patent for an HMD can be traced back to as early as 1916. As technology wasn't prepared to support such a mind-blowing idea at that time, it wasn't given special attention though. It was, once again military interests in 1929, which really got things in motion. The first mechanical flight simulator to train a pilot in a synthetic environment, that aimed to mimic real world situations, paved the way for virtual reality.[57]

Adding to the mechanical simulation of the flight simulator, Morton Heilig develops Sensorama in 1956. It was a multimodal experience display system, where a single person would see pre-recorded footage, combined with sound, smell, vibration and even wind. Four years later Heilig patents the first Stereoscopic-Television Apparatus for recreational use, bearing a striking similarity to modern HMDs.

The 1960s saw an increase in interest for simulation devices. The 'Sketchpad' application by Ivan Sutherland introduces the world to interactive computer graphics. Companies like General Motors Corporation would start researching interactive systems for automotive design. In 1968 Sutherland describes his development of 'A Head-mounted Three-dimensional Display', which uses CRT-screens to present separate images to each eye (**Figure 6**). This system provided stereoscopic images and ultrasonic tracking.[58]

It was until the 1970s and with the release of Atari's 'Pong'[59], that real-time interactive graphics reached the consumer market. Atari created a lab dedicated to researching ways to bring virtual reality devices to the consumer in 1981. In the same year at At&T Bell Labs, a

[57] Sherman / Craig (2003) 24-25.
[58] Sherman / Craig (2003) 25-27.
[59] Pong (1972).

'digital data entry glove interface device' was described. This device, which used light to register the amount of bending in the fingers and other gestures, as well as the overall orientation of the hand, can be seen as the first hand-tracking controller.[60]

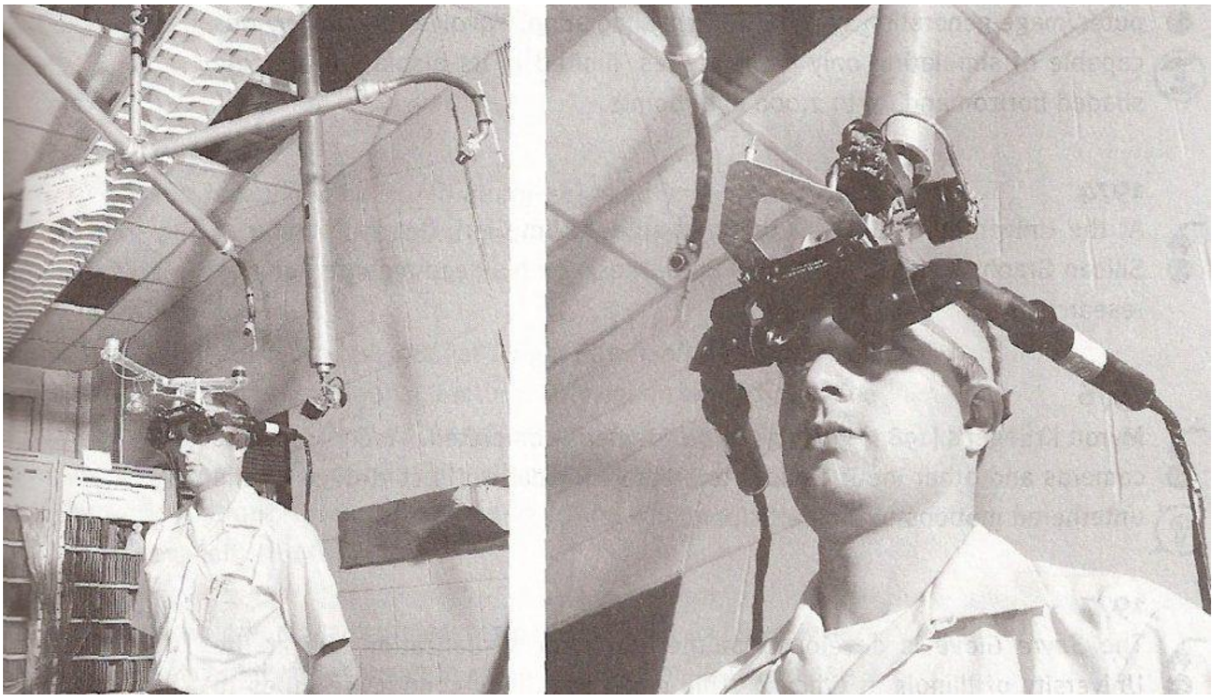

Figure 6
Ivan Sutherlands 'Head-mounted Three-dimensional display' featured stereoscopic visual images and ultrasonic tracking of the users position and look-direction.

The late 1980s further improved the formfactor of HMDs. Systems, that were actually sold, were highly sophisticated and even allowed more than one person to simultaneously share the same virtual environment, seeing avatar representations of each other. Those systems came with full stereo displays, head tracking, and hand tracking.

Since the 1980s, accessibility and a massive increase in computing power, changed the spread of VR, which was still being hold back by the immense costs and complexity of a system. The Aerospace Human Factors Research Division of NASA creates the Virtual Interface Environment Workstation (VIEW) in 1984. Many VR companies receive early funding through the work with the VIEW lab, including VPL, LEEP System, Fakespace and Crystal River Engineering.

It was until 1989 that the phrase 'virtual reality' was introduced by VPL, while announcing a complete Virtual Reality system. In the same year Autodesk announced their first 3D world creation solution to the press. The Powerglove, the first virtual reality home device is introduced by Mattel for the Nintendo home video game system, marking it as the first low-

[60] Sherman / Craig (2003) 27-29.

cost VR device for enthusiasts. Event though it was a failure, it introduced virtual reality to a huge range of customers for the first time. Connecting developers and enthusiasts at the first two official conferences specifically for VR in 1993, leads to an increasing interest in VR.

The following years see a rise in applications and a declining price of hardware. In 1995 Virtual I/O build an HMD below the $1000 price barrier with the VIO displays. These displays use an inertial tracking system to provide rotational information of the user’s head. The first six-sided CAVE-style display is inaugurated in Sweden in 1998. The VR-CUBE is constructed in Germany.[61] The 2000s marked the rise of VR with countless innovative products and developments:

> *“The first fifteen years of the 21st century has seen major, rapid advancement in the development of virtual reality. Computer technology, especially small and powerful mobile technologies, have exploded while prices are constantly driven down. The rise of smartphones with high-density displays and 3D graphics capabilities has enabled a generation of lightweight and practical virtual reality devices. The video game industry has continued to drive the development of consumer virtual reality unabated. Depth sensing cameras sensor suites, motion controllers and natural human interfaces are already a part of daily human computing tasks.”*[62]

On August 1st of 2012, a Kickstarter campaign launched, announcing the ‘Oculus Rift’ to the public. After three days, the campaign broke the one-million-dollar barrier. The first kit came at the extremely competitive price of $350. The next revisions of the kit came with superior features at low costs, finally making virtual reality available to everyone with a half decent PC.[63]

Systems with high-quality HMDs, six degrees of freedom head tracking, and even hands and feet tracking, now only cost a few hundred euros. The computer to drive a VR-Setup can be a mid-range PC, or, to some extent, even a laptop.[64]

Where did VR take off to reach the consumer market and which factors play an important role in this evolution? By combining the formerly established models we can investigate the development of VR.

[61] Sherman / Craig (2003) 29-35.
[62] https://www.vrs.org.uk/virtual-reality/history.html
[63] Kumparak (26.03.2014) https://techcrunch.com/2014/03/26/a-brief-history-of-oculus/
[64] Slater (2018) 431.

Applying the models

In this historical context the first artefact identified is the HMD from 1916, just like the low-wheeled formfactor prior to the high-wheeler, it was ahead of its time and not appreciated by society.

The stabilization of VR

The detour to the 1929's flight simulator showed a growing interest in simulating real world situations. By putting the development of VR in the graph (**Figure 7**), one can clearly see similarities to the bicycle, even though the technologies could not be more different. The flight simulator abandoned the head-mounted display and replaced it with a synthetic environment to train pilots. Inspired by the mechanical simulator Heilig, once again, added an HMD to the mix with his Sensorama, representing the first relevant artefact in this interpretation. By the 1980s countless technological features were implemented to further develop the formfactor. Atari introduced the first real-time interactive graphic device to the retail market, and started a video-game craze. The social groups of users and producers grew. The Powerglove showed the potential of low-cost VR devices for enthusiasts, forming a new target group, ignoring the fact of its failure. Soon companies began to try to push prices to make VR devices more affordable. After prices dropped and the Oculus Rift made its debut, the market stabilized and is growing ever since.

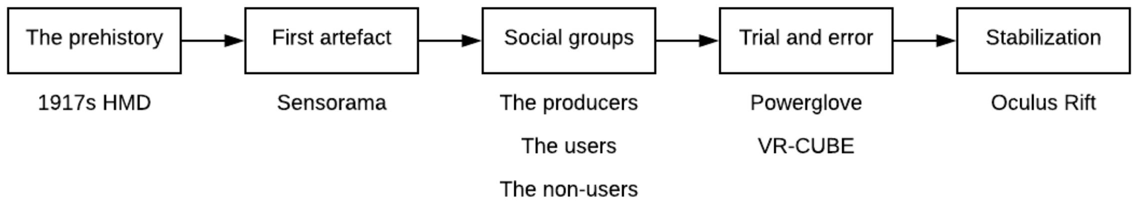

Figure 7
The development of VR is put into the first model, developed in the first chapter.

Determining the state VR is in proves to be less trivial, as Swann and Watts tell:

> *"VR has come to mean a lot of different things to different people. […] the computer interface, cinema, art, flight simulation, free thinking, and science fiction. […] VR draws on the experience and competencies of several different disciplines, industries and communities."* [65]

VR still exhibits many of the characteristics of a pre-paradigmatic technology. It is trying to achieve the necessary focus through collective action. The wide range of application may appeal to some at first, but is the main reason of VR that is holding back reaching the diffusion state.[66]

This may have been true in 2002, but since then the rules of VR have changed, as we've learned in our studies. Not only do we have dedicated applications like 'VR-Experiences'[67] or 'VR-Chats'[68], but also dedicated companies specialized in VR. Virtual Reality may still be in a pre-paradigmatic state to this day, but has made much progress in the last few years.

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[65] Swann / Watts (2009) 52.
[66] Swann / Watts (2009) 59.
[67] Plante (25.10.2017) https://www.inverse.com/article/37622-best-vr-virtual-reality-games-experiences-2017
[68] VR Chat (2017)

Conclusion

This research aimed to identify hidden arguments and small stories in technology development and adoption. It can be understood as a very brief compendium, covering two different approaches.

From Bijkers methods to analyse the detour of the high-wheeled bicycle, we formed a model which can be applied to other technologies. The author made us understand the role of the high-wheeled bicycle in relation to its successors. Each step we made told its own small story or argument. The focus on relevant social groups made us look at the non-users and how producers sought to reach them, as well as the problems of all social groups.

Swann and Watts taught us about the importance of having a common paradigm in technology adoption. There are lots of factors when it comes to growing a market or adopting a technology. Having analysed and interpreted the four steps the authors mention, we applied the model to the evolution of drones and UAVs. In conclusion, drones suited the purpose to show the importance of language, communication and networking among inventors and companies quite well.

In the last chapter we tried to mix both the models to analyse VR. Applying the model, inspired by Bijker, proved to be rather easy to do: Identifying the first artefact, moving on to social groups and their problems, and finally looking at its stabilization in the last 20 years. The meaning of VR changed rapidly throughout history. We can draw the conclusion that since the time Swann and Watts wrote about the paradigmatic state of VR in 2002, much has changed. Coming from cinema, arts and research, it made its way to the consumer-market with the introduction of affordable hardware. The Oculus Rift further stabilized its position.

VR is a technology with a very diverse and wide range of application. Reaching from simulation to casual fun, it came a long way. Comparing it to the bicycle or drones seems unfitting at first, but shows some crucial similarities in its evolution. In my opinion VR hasn’t reached its zenith yet. Maybe it will in the next 20 years, with our rapidly evolving and everchanging technology.

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Date: 10.01.2020 Signature:

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit eigenständig und ohne fremde Hilfe angefertigt habe. Textpassagen, die wörtlich oder dem Sinn nach auf Publikationen oder Vorträgen anderer Autoren beruhen, sind als solche kenntlich gemacht.

Datum: 10.01.2020 Unterschrift:

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Figures

Figure 1. The ‘STS Cycle’: Social values or needs promote what will be researched. Those results will then be engineered or developed into a technology which will then again be valued by society. Own figure.

Figure 2. The “Ariel” was patented in 1870 by J. Starley and W. Hillman. It is considered the first high-wheeled “Ordinary bicycle”. It is fitted with a lever that rotates the hub. Science Museum (07.04.2016): #TBT to the Ariel bicycle (commonly known as the Penny Farthing), which defined features of the ordinary bike.
https://twitter.com/sciencemuseum/status/718083423978414080 (accessed 10.01. 2020).

Figure 3. A model to investigate the evolution of technologies. Own figure.

Figure 4. The MQ-1 ‘Predator’ operated over 500.000 flight hours around the globe. It is a long endurance, medium altitude unmanned aircraft system for surveillance and reconnaissance. CleanPNG: General Atomics MQ-1 Predator Unmanned aerial vehicle Flugzeug-Drohne Streiks in Pakistan Militär - Drohnen PNG - 900*600. https://de.cleanpng.com/png-q1bss7/ (accessed 10.01. 2020).

Figure 5. A scheme showing the importance of forming or finding a common paradigm. This shows the ideal case, which is unlikely to be precisely met in reality. Own figure.

Figure 6. Ivan Sutherlands ‘Head-mounted Three-dimensional display’ featured stereoscopic visual images and ultrasonic tracking of the users position and look-direction. Ragonese, Valeria (06.06.2019): Virtual Reality. Like reality. But virtual. https://arvrjourney.com/virtual-reality-like-reality-but-virtual-ddb161891213 (accessed 10.01. 2020).

Figure 7. The development of VR is put into the first model, developed in the first chapter. Own figure.