# On groundbreaking innovations in weapons technology and the long wave

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The President:

Prof. Dr. Thomas Bieger

*Dedicated to Nikolai Kondratieff*

*I thank Professor Metz as well as Professor Hilb for their support and patience.*

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| | |
|---|---|
| % | per cent |
| ABC | Atanasoff Berry Computer |
| BRT | Bruttoregistertonnen |
| cm | centimeter |
| ICBM | Intercontinental ballistic missile |
| in | inch |
| IRBM | Intermediate Range Ballistic Missile |
| EDSAC | Electronic Delay Storage Automatic Calculator |
| EDVAC | Electronic Discrete Variable Arithmetic Computer |
| EMP | Electromagnetic pulse |
| ENIAC | Electronic Numerical Integrator and Computer |
| FM | Frequency Modulation |
| FTSE 100 | Financial Times Stock Exchange 100 Index |
| GBP | Pound Sterling |
| GNP | Gross National Product |
| MAD | Mutual Assured Destruction |
| MIRV | Multiple Independently Targetable Reentry Vehicles |
| mm | millimeter |
| m.p.h. | miles per hour |
| n/a | not available |
| R&D | research and development |
| RAND | research and development |
| S&P 500 | Standard & Poor's 500 Index |
| SAC | Strategic Air Command |
| SLBM | Submarine Launched Ballistic Missile |
| TACFIRE | Tactical Fire Direction System |
| UNICOM | Universal Integrated Communications System |
| UNIVAC | Universal Automatic Computer |
| USA | United States of America |

# Abstract

Researchers like Schumpeter (2008) or Nefiodow and Nefiodow (2014) mention the interconnection between weapons technology and the general technological reality of the Kondratieff cycle. The precise relationship is somewhat unclear, however. A better understanding would not only extend the knowledge regarding the Kondratieff cycle but might help to develop what van Creveld (1991) asked for: the "… systematic, comprehensive theory of the relationship between technology and war …" that has not been developed yet (p. 323).

Overall, groundbreaking innovations in weapons technology should be related to the general technological reality. However, certain deviations have to be expected as meaningful developments took place during the last two centuries like the rise of the R&D sector.

The Kondratieff cycle includes elements like war, economic development, and the general technological development, which are useful for the analysis of this dissertation because they have an influence on weapons technology. The orthodox Kondratieff cycle is not solid enough to be used, however. Therefore, the mentioned parts are synthetically reconstructed and used as a fundament.

Based upon a framework of 10-year rolling returns of the S&P 500 from 1789 to 2017, a set of major wars, as well as the technological reality of the last two centuries, a part of the orthodox Kondratieff cycle is synthesized. The results suggest that Kondratieff was by and large right regarding the dating of his cycles. An explanation of the impact of major wars on the economy makes clear that they are accompanied by meaningful price increases. The price peaks of Kondratieff's cycle during the time frame of his analysis are almost all accompanied by large wars and might therefore be to a meaningful extent triggered by the wars.

Based upon the mentioned framework, the emergence of groundbreaking innovations in weapons technology over time with regard to the long wave, major wars, as well as the general technological reality is examined. First of all, the rise of the single innovations is analyzed and a date is determined, which represents the year of emergence. In a second step, their rise to full-scale application is examined by looking at production data, changes in strategy and tactics, and so forth.

The question how the groundbreaking innovations in weapons technology have arisen over time is answered by adopting the procedure used by Mensch (1975): the emergence of innovations per decade over time is shown and compared to his results.

In general, groundbreaking innovations in weapons technology have occurred in clusters like general ones. A certain amount has emerged around the troughs of the

long wave, which is in line with the clusters of general innovations. Clusters show up close to major wars as well, which is especially the case during the First and Second World War, which is in line with the rise of the R&D sector. Regarding the question how groundbreaking innovations in weapons technology reached full-scale application, some experienced a slow rise, while others were rather paradigm changes. Moreover, the groundbreaking innovations in weapons technology are loosely related to the general technological reality, for example wireless communications and radar to advances in electricity and electrical engineering. An orthodox general cohesion does not exist, however.

# Zusammenfassung

Forscher wie Schumpter (2008) oder Nefiodow und Nefiodow (2014) erwähnen den Zusammenhang zwischen der generellen technologischen Realität des Kondratieffzyklus und der Waffentechnik. Der genaue Zusammenhang ist jedoch etwas unklar. Ein verbessertes Verständnis würde nicht nur das Wissen um den Kondratieffzyklus vertiefen, sondern auch helfen, die von van Creveld (1991) vorgeschlagene „... systematische, umfassende Theorie des Zusammenhangs zwischen Technologie und Krieg ... (eigene Übersetzung)“ zu entwickeln, was noch nicht geschehen ist (p. 323).

Grundsätzlich sollten die bahnbrechenden Innovationen in der Waffentechnik in einem Zusammenhang mit der allgemeinen technologischen Realität stehen. Allerdings sind gewisse Abweichungen zu erwarten, da in den letzten zwei Jahrhunderten bedeutungsschwere Entwicklungen stattgefunden haben, wie etwa die Entstehung des R&D Sektors.

Der Kondratieffzyklus beinhaltet Elemente wie Krieg, ökonomische Entwicklung und die generelle technologische Entwicklung. Sie alle sind nützlich für die Aufgabenstellung dieser Dissertation, da sie einen Einfluss auf die Waffentechnologie haben. Das ursprüngliche Konzept des Kondratieffzyklus ist allerdings nicht solide genug, um für weitere Arbeiten genutzt zu werden. Daher werden die benötigten Elemente in soliderer Art und Weise nachgebaut und als Fundament genutzt.

Dazu werden folgende Schritte unternommen: Bestimmung der rollierenden Rendite mit der Periode zehn Jahre für den S&P 500 von 1789 bis 2017. Weiterhin folgen die Auswahl von bedeutenden Kriegen sowie die Definition der technologischen Realität. Die Ergebnisse legen nahe, dass die Datierungen von Kondratieff die lange Welle betreffend selbst mit dem hier verwendeten Indikator grosso modo reproduzierbar sind. Im theoretischen Teil werden die Auswirkungen von Kriegen auf die Wirtschaft erklärt und es wird deutlich, dass sie in der Regel mit starken Preissteigerungen einhergehen. Im Beobachtungszeitraum von Kondratieff liegen fast alle Preisgipfel zeitlich in der Nähe von bedeutenden Kriegen, die als maßgeblich für die Preissteigerungen verantwortlich anzusehen sind.

Vor diesem Hintergrund wird das Auftreten der bahnbrechenden Innovationen in der Waffentechnik im Zusammenhang mit der langen Welle, bedeutenden Kriegen, sowie der generellen technologischen Realität untersucht. Zuerst wird die Entwicklung der einzelnen Innovationen analysiert und jeweils ein Entstehungsjahr bestimmt. In einem zweiten Schritt wird die anschließende Ausbreitung unter Zuhilfenahme unter anderem von Produktionszahlen oder Änderungen in Strategie und Taktik untersucht.

Die Frage nach dem Muster des Auftretens im Zeitverlauf wird beantwortet, indem das Verfahren von Mensch (1975) auf diesen Bereich angewendet wird: Das Auftreten der Innovationen pro Dekade wird grafisch dargestellt und mit den Ergebnissen von Mensch (1975) verglichen. Es lässt sich feststellen, dass die bahnbrechenden Innovationen im Bereich der Waffentechnik ebenso wie die allgemeinen Innovationen in Schwärmen auftreten. Ebenso wie bei den Letztgenannten liegen diese Schwärme zum Teil im Bereich der unteren Wendepunkte der langen Welle. Teilweise liegen sie aber auch in der Nähe der bedeutenden Kriege, was insbesondere auf den Ersten und Zweiten Weltkrieg zutrifft. Diese Erscheinung deckt sich mit der Entstehung des R&D Sektors zu Beginn des 20. Jahrhunderts. Manche Innovationen stellen Paradigmenwechsel dar, während sich andere nur langsam durchgesetzt haben. Insgesamt lässt sich festhalten, dass die bahnbrechenden Innovationen in der Waffentechnik selbstverständlich mit der allgemeinen technologischen Realität verknüpft sind. Ein Beispiel ist etwa das Radar, dessen Entwicklung mit dem technologischen Fortschritt im Bereich der Elektrizität und Elektrotechnik zusammenhängt. Ein orthodoxer genereller Zusammenhang findet sich jedoch nicht.

# 1. Introductory part

The topic of this dissertation plays a small role in recent academic as well as public discussions only. There are two main reasons: firstly is the Kondratieff cycle a topic, which does not deal with cyclicality only but also is the awareness for the topic according to van Duijn (1983) cyclic and bound to times of economic crisis and standstill like the 1930s and 1970s. However, even though cyclicality in the narrower sense does not exist in this field, a severe economic crisis will occur sooner or later.
Secondly, war is a topic that fortunately did not play the role it played until the Second World War in the Western World. However, Cirillo and Taleb (2016) recently concluded that, in contrast to popular opinion, no change to the better has occurred in the area of battle casualties in the world. Usually, "tail risks" with regard to battle fatalities are underrated (pp. 1–2, 7, 12). At the same time, the oldest picture showing human beings fight is about 20,000 years old (O'Connell, 1989, pp. 26–27), which suggests that conflict is something that has been connected to mankind perhaps from the very beginning. Overall, dealing with a topic that is out of favor presumably temporarily only might bring some useful insights.
Especially from the background of renewed tensions in the world after the time of relaxation following the collapse of the Soviet Union, a larger armed conflict might be possible. Historically, the decline of major powers was usually accompanied by armed conflicts (Modelski, 1978, pp. 214–217). Therefore, the obvious vaning dominance of the USA seems to come along with potential for war. The most important countries that challenged the global position of the USA were Russia and China in the recent past. Furthermore, they questioned the status of the USD as the most important currency in the world. A great disadvantage would arise for the USA, should the USD lose its global position.
In economic terms, the world suffered from a meaningful crisis around the year 2008, which had a lasting impact on many countries. Moreover, we have unprecedented and presumably unsustainable debt levels, dubious economic growth and unique central bank policies including the lowest interest rates in the history of mankind. Commodity prices bottomed out around the year 2000 and are despite meaningful corrections still elevated. It seems as if interest rates bottomed out recently as well, which would not bode well for a world with the debt levels we are facing today. Usually, tops in commodity prices regarding long-term price swings come along with war and economic problems. Examples during the last two hundred years are the top around 1815 with the Napoleonic Wars, the one of about 1865–1870 that accompanied the American Civil War and the Franco-Prussian War and the one of about 1920 with the First World War. The most recent one topping out in the late 1970s and early 1980s

came along with the Vietnam War and economically difficult times until the early 1980s. Based upon the history of the last two centuries, it seems plausible to expect another inflationary period that might come along with belligerent times during the next ten to twenty years.

## 1.1. Meaning for research and practice

The main goal of this dissertation is to gain a better understanding of the emergence and the spreading of innovations in the area of weapons technology and their connection to major wars, the general technological reality, as well as the long wave. Apparently, some kind of connection exists with regard to the technological development related to the Kondratieff cycle. It does not only contribute a brick to the knowledge regarding the Kondratieff cycle but provides a better understanding of history in general as well.

### 1.1.1. Meaning for research

Literature related to the Kondratieff cycle is the first and most important field of research this dissertation contributes to as it closes a gap in the literature dealing with the Kondratieff cycle in a broader sense. Many researchers mention a connection between innovations in the area of weapons technology and general innovations or at least how weapons are affected by general innovations. Schumpeter (2008) for example mentions Krupp's role in the steel business and points towards the fact that he was the first to produce "cannons made of cast steel (own translation)" in 1856 (p. 367). Another example is Nefiodow & Nefiodow (2014) who mention the connection between the second Kondratieff cycle, which was dominated by steel and the meaning of it for constructing weapons. For what they name the fifth Kondratieff cycle, which was dominated by information technology, they mention its application for "modern military systems (tanks, frigates, fighter aircraft, etc) (own translation)" (pp. 6, 202–204). However, a detailed study is not available yet. Therefore, the goal of this dissertation is a better understanding of the connection between groundbreaking innovations in the area of weapons technology and general innovations.

The meaning for research is at the same time the main motivation for this dissertation and its topic: the orthodox Kondratieff cycle is a fascinating field, which includes a variety of different phenomena. Many of them were subject to research and a lot of literature exists for example in the area related to the Kondratieff cycle and technology. As the occurrence of wars and technological development are both elements of the orthodox concept, an amalgamation looks like a promising field.

A further point worth mentioning is the fact that the research analyzing the Kondratieff cycle in relation to technology focuses by and large on general technology, which is quite useful for explaining economic development in general. Looking at weapons technology adds a further aspect to the mentioned field of research.
Literature related to peace research should profit as well. Many studies from the field focus for good reasons on single innovations or on relatively short periods of time only. Having a time frame of almost two centuries like in this dissertation can therefore provide an overview from the background of the Kondratieff cycle. This dissertation augments the findings by peace researchers like Väyrynen and Kaldor as well, who combined the Kondratieff cycle and peace research earlier on already.

### 1.1.2. Meaning for practice

To some, history is interesting as it might deliver clues about how the future might look like. With regard to the topic of this dissertation, the Crimean War as well as the American Civil War provide examples: concerning the first, McNeill (1984) argues that the "siege of Sevastopol" can be seen as a blueprint for the battles in the West during the First World War as it displayed many characteristics of the latter already: "trench systems, field fortifications, and artillery barrages … Only the machine gun was missing" (p. 230). Regarding the latter, Mc Neill (1984) writes that it was not seen as representative for future warfare by most observers from Europe but in fact it was some kind of blueprint for the First World War with the utilization of "machine-made arms" and "railroads", overall "an industrialized war" (pp. 242–243). What the mentioned cases suggest is that during the wars occurring on the top of one Kondratieff cycle, the patterns dominating the reality of the wars during the next peak arise. This view is tempting but seems to simplistic: as Kleinknecht (1981) explains is it necessary that the cycles really exist and furthermore is a "theoretical explanation of the causes (own translation)" that replicate them needed for using the cycles as a tool for forecasting (pp. 111–112). Craig and Watt (1985) argue for another, related case. They provide a sketchy overview regarding the relationship between the Kondratieff cycle as defined by van Duijn and casualty data. They find that during times of a peaking Kondratieff cycle, also the numbers of casualties are high. They suggest using this correlation for predictions regarding the future and opine that high casualty numbers around the year 2000 are on the cards (pp. 25–27). Even though the study is not very detailed and they assume a persisting cyclicality, their message that a connection between the Kondratieff cycle and casualty numbers exists should not be neglected. Even though the inexistence of a strong cyclicality concerning the

Kondratieff cycle is beyond dispute, a deepened understanding of the relationship between major wars and the Kondratieff cycle is unquestionably worthwhile. Especially as this dissertation builds upon a clear-cut and solid fundament and dependable data, the result is more precise than many earlier contributions.

## 1.2. Objective

Mensch (1981) argues that his work is in conformity with Popper "logico-deductive" because he tries to falsify his hypothesis (p. 174). Also this dissertation should be seen in line with Popper's (2000, pp. 15–45) view. It is not intended to prove anything but rather to see if the results falsify the theory constructed below in part 2, which tries to explain the emergence of groundbreaking innovations during the time frame of this dissertation.

## 1.3. Procedure

The definitions used in this dissertation are as solid as possible. The justified critique brought forward against earlier works is comprised and the implications are considered. Firstly, part 2.1. covers the definitions needed. It starts with defining the time frame and the countries under analysis. It proceeds by explaining the Kondratieff cycle and why the orthodox concept of it is not suited as a fundament for further work. Therefore, parts of the orthodox Kondratieff cycle are reconstructed, which is much more solid than most of the myriad definitions available. Firstly, rolling returns of the S&P 500 from 1789 to 2017 are used for dating the long waves, which is a relatively new procedure. Secondly, building upon the work of Levy (1983) enables a selection procedure of major wars with a minimum amount of arbitrariness. Thirdly, to take into consideration the general technological development over time, the work of Nefiodow and Nefiodow (2014) is included as well. The next major point explains how Mensch (1975) defined "basis innovations", how his work was criticized and how a set of groundbreaking innovations in weapons technology can be defined upon the mentioned insights.

The remaining chapters of the general theoretical part deal with the influence of war on the economy and innovations. Furthermore, an overview regarding relevant literature from the areas of the Kondratieff cycle, peace research, and military literature follows. Finally, a theory of the emergence of groundbreaking innovations in weapons technology is constructed.

The part focusing on empirical research explains the research questions, the research methods as well as the results. It further defines the target group of this dissertation as well as its limitations. The added set by Dupuy (1990) is of special importance. It enables testing the results of this dissertation regarding the set of innovations and the dating of their emergence. The last part discusses the results, their implications for further research, as well as for practice.

# 2. General theoretical part

Van Creveld (1991) writes, "… a systematic, comprehensive theory of the relationship between technology and war is still not available. It would be highly desirable, and writing it would present an appropriate challenge for a new Clausewitz" (p. 323). Even though this dissertation cannot present the work of a new Clausewitz, the goal is nevertheless to provide more clarity concerning the interrelationship he mentions. However, it seems too simplistic to look at technology and war only, as also other factors play a meaningful role. Implementing them as well should establish a certain level of comprehensiveness at least. Therefore, parts of the orthodox Kondratieff cycle seem to be a good choice as they are closely related to the topic. War, economic development, the emergence of general innovations, and groundbreaking innovations in weapons technology are the elements used in this dissertation.

First of all, the necessary definitions follow below. They are: time frame of this dissertation, countries under analysis, Kondratieff cycle, major wars, technological development over time, groundbreaking innovations in weapons technology and their rise to full-scale application.

Furthermore, the economy has an influence on war. Economic strength of a state should by and large enable a strong military force and the development and application of innovative arms. This assumption is based upon the history of the last two centuries: Great Britain had a strong economic position during the 19th century, which came along with a strong military position. The same applies to the USA during the 20th century. A brief discussion can be found below in chapter 2.1.1.

As war has a certain effect on the economy as well, some remarks follow below to provide a rough picture of the nature of the war economy in Great Britain and the USA during the First and Second World War. Furthermore, two especially important developments are addressed: state interventions during belligerent times, which increased ever since the French Revolution and the rise of the R&D sector ever since the First World War. Especially during the Second World War, state interventions were heavy and at the same time, the rise of R&D changed the nature of the development of technological progress meaningfully. Additionally, war has a certain impact on innovative activity; this is especially true for the 20th century.

From the literature related to the Kondratieff cycle, two fields are addressed: firstly, authors focusing on war and the Kondratieff cycle like von Ciriacy-Wantrup (1936) and authors focusing on technological development and economic growth like Schumpeter (2008) and Mensch (1975).

Another important point that is discussed below is the cohesion between military innovations and general innovations, as they are to some extent interrelated. For a

better understanding of military innovations, peace research and military literature is included as well.
Finally, a theory is developed to explain the rise of groundbreaking innovations during the time frame of this dissertation. Economic factors, wars, technological development, as well as state interventions and the rise of the R&D sector are taken into consideration.

## 2.1. Theories related to the topic of this dissertation

This chapter provides definitions and explanations regarding the used theories, time period, and so forth. The clear-cut definitions serve as a fundament for the empirical research later on.

### 2.1.1. Time frame of this dissertation and countries under analysis

The time frame covers the period from 1800 until today. It is a period for which reliable data is available and also is the starting point set to cover the time ever since the Industrial Revolution. Furthermore, it is in accordance with the beginning of the period covered by Kondratieff. It is also in line with the work of later researchers in the area of the Kondratieff cycle who used the same time frame. The end of the period makes it possible to judge the rise of military innovations that appeared during the Second World War over the following decades. However, only groundbreaking innovations in weapons technology that arose until the end of the Second World War are included. Stretching the period towards the more recent past would impair the strength of this dissertation as judging developments that are not finished yet is connected to more uncertainty than judging the development of for example the percussion cap, which appeared about 200 years ago.
It is useful to focus on the countries that were most powerful during the time frame covered. Great Britain dominated the world from about 1800 to 1900 and subsequently the United States did so for the next 100 years (Modelski, 2006, p. 293). Modelski (1978) provides a theoretical background for his judgment with his "global political system", which according to him can be described as "… the institutions and arrangements for the management of global problems or relations …". It started to exist about 500 years ago. An important characteristic of the system is that there is no single power ruling it. However, powerful players, so called "world powers" in the game exist that have the power to dominate the "global political system". They can be described as "… those units monopolizing (that is, controlling more than half of) the market for (or supply of) order-keeping in the global layer of interdependence." The

process of rise and decline of the “world powers” is cyclic. Usually, they emerge from an unorganized state of the “world system”, which becomes a major and long-lasting war. The future “world power” gains its superior position during that conflict, which it keeps for the time to come. Finally however, other powers start to compete for the role of “world power”, which again brings the state of conflict mentioned above and usually the rise of a new “world power”. The time frame of this process is about one century (pp. 214–217). Modelski (1978) identifies four “world powers” ever since 1500: Portugal, United Provinces of the Netherlands, Great Britain and the United States of America. Only Great Britain was in that role two times. The first time started during what he calls “French Wars (1688–1713)” and the second one after the “French wars (1792–1815)”. The USA arose as “world power” from the “German wars (1914–1918, 1939–1945)” and is in power ever since (pp. 221–225).
However, some groundbreaking innovations in weapons technology emerged from other countries than Great Britain and the USA. An example is the breech-loading rifle. In such cases, the development of the innovation in the country of its origin is analyzed. Additionally, a description of the adoption in the USA and Great Britain follows.

### 2.1.2. The Kondratieff cycle

Usually, the terms “Kondratieff cycle” and “long wave” are used synonymously, which is also the case in this dissertation. The orthodox Kondratieff cycle covers a variety of socio-economic observations depending on a long-term cycle. However, Nikolai Kondratieff was not the first who published on the phenomenon of long waves. Already the Book of Leviticus describes a 50-year cycle regarding the jubilee year.

#### 2.1.2.1. Predecessors and the meaning of Nikolai Kondratieff

The first one to suggest a cycle with a length of 54 years might have been Clark in 1847 (van Duijn, 1983, p. 59). Weinstock (1964) explains that during the early decades of the 20$^{th}$ century, many authors including Tugan-Baranowsky and Wicksell contributed to a varying extent to the topic of long-term economic cycles. However, the first authors writing extensively on the topic were van Gelderen in 1913 and de Wolff in 1924 (pp. 18–34). Kondratieff’s publications on the topic date from 1922 to 1928 (Garvy, 1943, p. 203). Not only saw Schumpeter (2008) Kondratieff as the preeminent researcher in the field of the Kondratieff cycle (p. 174), but also does

Schumpeter himself build to a meaningful extent on the Kondratieff cycle in his 1939 work "Business cycles".

#### 2.1.2.2. The work of Nikolai Kondratieff

Kondratieff (1926) analyzes data regarding Great Britain, France, the USA, and in a few cases Germany for the time frame from about 1790 to 1920. He finds a cycle with a length between 47 to 60 years in different series like price indices, wages, and interest rates. Furthermore, he argues that the rising part of the wave is an economically more prosperous time than the falling part. The falling part is usually also a time of severe crises in the agricultural sector but also a time of technical inventions. The rising part is by tendency a time of rising gold production and new countries entering the global market. It is also the period during which by tendency most wars occur. However, even though the mentioned items technical innovations, wars, inclusion of new countries into the global market as well as changes in gold production have an impact on the economy, they are rather effect than cause with regard to the Kondratieff cycle (pp. 573–609). Kondratieff (1928) sees the cause for the Kondratieff cycle rather in the process of accumulation of capital goods. The production of capital goods takes time and occurs in clusters. Furthermore, it depends on four factors: "high intensity of the activity of saving (own translation)", "large supply of cheap capital available (own translation)", "accumulation of this capital by powerful companies and financial centers (own translation)" as well as "a low level of prices of goods, which fuels the activity of saving and long-term capital goods (own translation)". This is usually the case during the falling part of the Kondratieff cycle, which therefore enables another rising part (pp. 36–38).

Kondratieff (1926) mentions the following turning points of the Kondratieff cycle: peaks around 1810–1817, 1870–1875, and 1914–1920 as well as troughs in the late 1780s to early 1790s, 1844–1851, and 1890–1896 (p. 590).

#### 2.1.2.3. Critique regarding Kondratieff's work

Kondratieff's work has provoked a considerable amount of critique ever since publication. Even though the early critique by Russian economists was to a meaningful extent ideologically influenced (Garvy, 1943, p. 216), critics elaborated important weaknesses.

The work by Weinstock is a solid as well as comprehensive discussion of the Kondratieff cycle. Weinstock (1964) suggests five major points of critique: "statistical methods (own translation)", "evidence of the statistical findings (own translation)", “regularity of the proved swings (own translation)”, “impulses of the long waves (own translation)”, as well as “the theory of long waves in the narrower sense (own translation)” and builds heavily upon the critique by Garvy (1943) and the Russian critics he mentions (pp. 48–62). Overall, Weinstock (1964) concludes that the Kondratieff cycle does not exist (p. 124).

Concerning the “**statistical methods** (own translation)”, Weinstock (1964) points towards Kondratieff’s arbitrary way of using them with regard to the different series. Neither does Kondratieff treat the series he presents with the same statistical methods nor does he offer an explanation for the unequal treatment. The main problem is how to deal with the “trend (own translation)”. Weinstock concludes: “A method for trend elimination especially for the depiction of long waves has not been developed; therefore the problem remained basically unsolved (own translation)” (pp. 48–50).

Weinstock’s (1964) critique bundled in the point “**evidence of the statistical findings** (own translation)” is mostly directed against the data used, the results, as well as Kondratieff’s unsystematic procedure. Kondratieff uses 36 data sets, 15 of them represent prices and the rest quantities. Kondratieff finds the long wave in all but one of the price series but only in half of the sets concerning quantities. Furthermore, most series do not cover the whole period from 1790 to 1920 but only a fraction of it; actually do only four price series cover the whole period. Two of them are “wholesale price indices (own translation)”, which are, according to Weinstock, of limited meaningfulness only. Kondratieff’s arbitrary procedure is for example reflected by the facts that he does not explain why the series he presents are used or that he treats trade data for different countries differently (pp. 50–53).

Regarding the point “**regularity of the proved swings** (own translation)”, Weinstock (1964) doubts the regularity of Kondratieff’s results concerning the Kondratieff cycle and stresses his arbitrary work when determining the turning points. Furthermore, he argues with Garvy (1943) that the Kondratieff cycle could also be nothing more than the appearance of severe occurrences of a shorter-term phenomenon (Garvy, 1943, p. 218). Overall, Kondratieff failed to prove the Kondratieff cycle (pp. 53–55).

With regard to the “**impulses of the long waves** (own translation)”, Weinstock (1964) mostly builds upon Garvy’s (1943) collection of critique by Russian economists. Kondratieff’s argument that the rising part of the wave is usually accompanied by good economic times was addressed by Gerzstein, who confronted it with examples where it was in reverse and also with an example where the situation was out of sync in different economies as an attempt to destroy the globality of the Kondratieff cycle (Garvy, 1943, p. 212). The critic Oparin accused Kondratieff’s procedure when dealing with “inventions” and their temporal occurrence as little systematic and put doubt on the suggested pattern in which they occur according to Kondratieff and addressed similar critique to the topic armed conflicts and social upheavals, where especially no weighting of the events took place (Garvey, 1943, p. 212). Furthermore, the arguments of the “inclusion of new countries into the global market (own translation)” as well as the one regarding the existence of patterns in gold production have to be rejected (pp. 55–59).

The major point Weinstock (1964) advances against “**the theory of long waves in the narrower sense** (own translation)” is that Kondratieff sees innovations as something caused by the wave, therefore the explanation of the Kondratieff cycle delivered by Kondratieff is valid for “replacement investments (own translation)” only. That seems to be a doubtful explanation, especially as it is also questionable that funds available for loans stay unused for long, also is Kondratieff’s related empirical evidence very limited (pp. 59–60).

The above-mentioned points by the critics are valid and show weaknesses of Kondratieff’s work. Overall, the conclusion can be drawn that the orthodox concept of the Kondratieff cycle as suggested by Kondratieff himself is too weak to be used as a fundament for further work. However, the conclusion that every part of the Kondratieff cycle should be rejected right away is premature as solid later research confirmed parts of Kondratieff’s work.

#### 2.1.2.4. Long waves in rolling returns of the S&P 500 from 1789 to 2017

Kondratieff’s statistical work provoked a lot of critique, as discussed above. However, the same is true for later attempts to prove or reject the existence of the Kondratieff cycle in different time series. Gerster (1988) provides an overview regarding earlier studies and their findings. In a nutshell, different authors using different methods present totally diverging results. The application of spectral analysis did not overcome this situation as it is also dependent on an “adequate trend elimination (own translation)” (pp. 5–16, 24). Two main problems make the analysis of long waves difficult: the scarcity of reliable data over a longer period of time as well as the adequate “determination of the trend (own translation)” regarding the analyzed time series (Gerster, 1988, pp. 45, 82). Gerster’s work is dated but the message remains valid: the existence of long waves is subject of heavy debates until today. Furthermore, the results vary meaningfully concerning different series like prices, GDP data, and so forth. A related problem is the one of exogenous shocks. Metz (2006) discusses it with regard to statistical evidence of the Kondratieff cycle. Examples of such “exogenous shocks” are the First and Second World War as well as the economic crisis of the 1930s. He takes into consideration the mentioned shocks and finds steady growth concerning the “GDP per capita” for the USA and a cyclic one for France, Italy, as well as Great Britain. The growth cycles do not have the length of Kondratieff cycles and are inversely correlated to the emergence of innovations (pp. 91–92, 94–95).

Weinstock (1964) criticizes Kondratieff for not explaining why the used data found application (p. 52). Here, the data is chosen carefully according to the aim: as explained in chapter 2.1.1. above, the focus is on the countries USA and Great Britain during the time frame 1800 until today. The S&P 500 is an important stock market index, which represents economic development in the USA. As the global meaning of the USA rose during the 19th century and reached a dominating position approximatively during the First World War, it is acceptable to use the index for dating the long wave during the whole time frame of this dissertation and for both countries. The index is especially interesting as data for the whole period 1789 until today exists, which is not the case for the British FTSE 100.

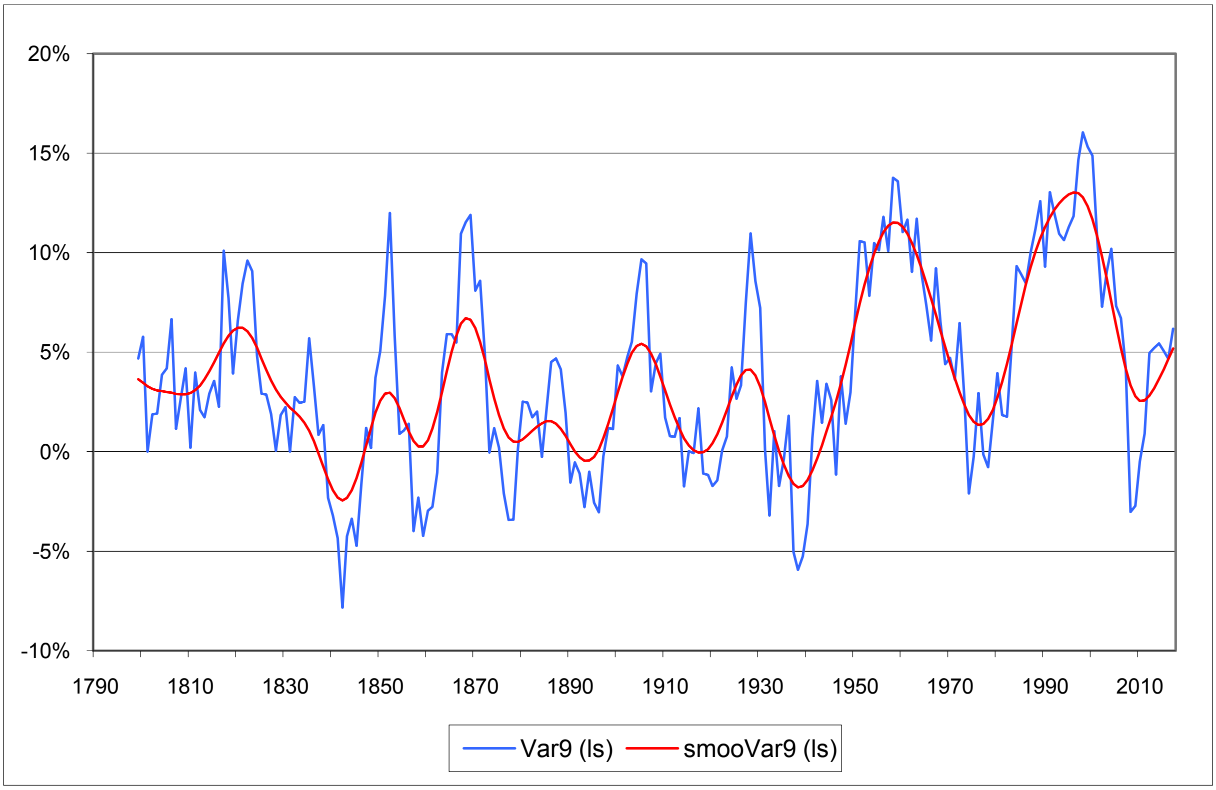


**Figure 1:** 10-year rolling return of the S&P 500, 1789–2017. (Own depiction, based upon Allianz, 2010. Calculations based upon https://stooq.com/q/d/?s=^spx&i=y. Smoothed with a Hodrick-Prescott filter, λ=100.)

Using rolling stock market returns is a relatively new way of dating the long wave. Allianz (2010) suggested such a dating procedure (p. 6) and inspired the framework of this dissertation. The figure above shows the rolling returns for the whole time frame. The dates for the lower turning points of the long wave can be determined as follows: 1840s with a low in 1842, 1890s with a low in 1896, 1930s with a low in 1938, 1970s with a low in 1974, 2000s with a low in 2008. The question regarding the theoretical meaning of the used indicator 10-year rolling return of an important stock market index can be answered by pointing towards Mensch's (1975) "metamorphosis model", which is explained in part 2.3.2.3. below. The next figure suggests a high level of plausibility of the indicator 10-year rolling return of the S&P 500: a large number of "basis innovations" can be observed during the late stages of the long waves or even temporally closely connected to their lower turning points.

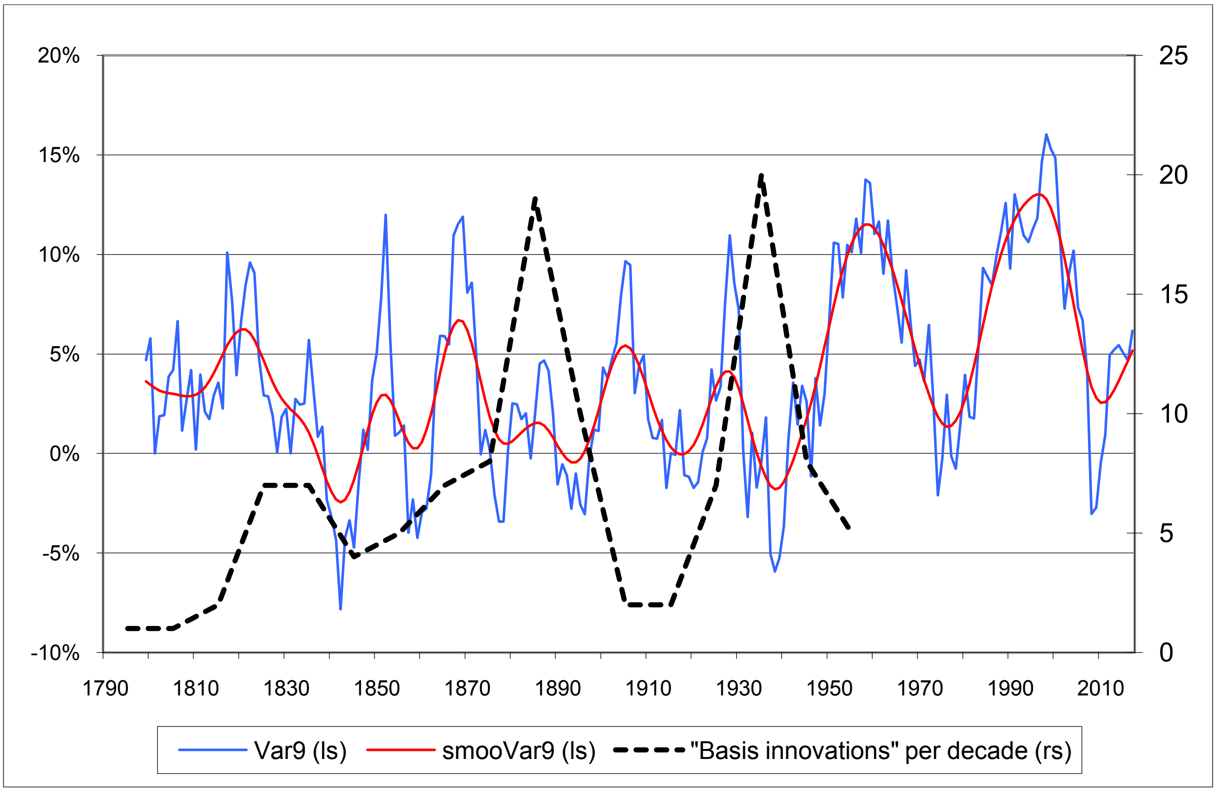


**Figure 2:** 10-year rolling return of the S&P 500, 1789–2017 and "basis innovations" according to Mensch per decade. (Own depiction, based upon Allianz, 2010. Calculations based upon https://stooq.com/q/d/?s=^spx&i=y. Smoothed with a Hodrick-Prescott filter, λ=100. Occurrence of basis innovations based upon Mensch, 1975, pp. 135–139)

### 2.1.3. Major wars

Garvy (1943) criticizes Kondratieff's procedure regarding the occurrence of armed conflicts as he simply presents a collection of them. "No attempt was made by Kondratieff to evaluate the importance of the events … listed" (p. 207). A certain categorization of the wars that took place during the period covered by this dissertation has therefore to happen to overcome this weakness and to avoid as much arbitrariness as possible.

The formulation "major wars" is used to distinguish the ones with a higher impact from ones that were less meaningful. It is beyond dispute that war disrupts the life of mankind. First and foremost is the life of soldiers and civilians exposed to danger, as well as their emotional well-being. Secondly, capital goods related to all three sectors of production are exposed to destruction. Thirdly, as a consequence of the aforementioned, the processes of production and distribution are interrupted and may also come to a halt. The effect can be complete misery of the population. Therefore, it becomes very clear that every war is bad and linked to a meaningful amount of negative effects. However, as explained in the beginning of this dissertation, war has been a part of mankind for a long time. Dealing with them as a part of the reality comes along with the problem of measuring their impact. Many different measures are possible like for example casualty data or estimates of economic damage. Taking into consideration the critique by Garvy as cited above, casualty data is chosen for this dissertation. The mentioned normative limitations apply.

#### 2.1.3.1. Levy's set of "great power wars"

Levy (1983) offers a data set covering the time frame from 1495 to 1975. It includes the 119 wars in which "great powers" participated and therefore leaves aside relatively unimportant smaller ones. "Civil wars" and "imperial or colonial wars" are not included (Levy, 1983, p. 51). The wars with participation of a "great power" are meaningful because the latter are powerful players in the "modern great power system", took part in many wars, and wars with their engagement usually show a high amount of casualties (Levy, 1983, pp. 3, 8–9). According to Levy (1983), the "modern great power system" came into existence in about 1500 and is ruled and shaped by the especially mighty players, the "great powers". The main issues of the system are "power and security relations" (pp. 8–9). Levy (1983) defines a "great power" as following:

… a state that plays a major role in international politics with respect to security-related issues. The Great Powers can be differentiated from other states by their military power, their interests, their behavior in general and interactions with other Powers, other Powers' perception of them, and some formal criteria. (p. 16)

"War" is defined as "a substantial armed conflict between the organized military forces of independent political units" (Levy, 1983, p. 51). For the criterion "great power war", there have to be at least 100 dead soldiers of one "great power" or 1,000 soldiers of the latter fighting in the war (Levy, 1983, p. 74). The measure for the wars chosen is what Levy (1983) calls "severity": casualties of the "great powers" from actual fighting, not including non-combatant casualties (p. 83).

### 2.1.3.2. Wars of the "great powers" USA and Great Britain

His scheme of "great powers" includes Great Britain during the whole time frame 1495 to 1975, and the USA from 1898 to 1975. Figures 3 and 4 represent all wars from Levy's (1983) list with participation of either the "great power" Great Britain or the USA during the time frame of this dissertation. However, wars with a "severity" of 1,000 or less like the Sinai War are omitted, as their influence should have been marginal.

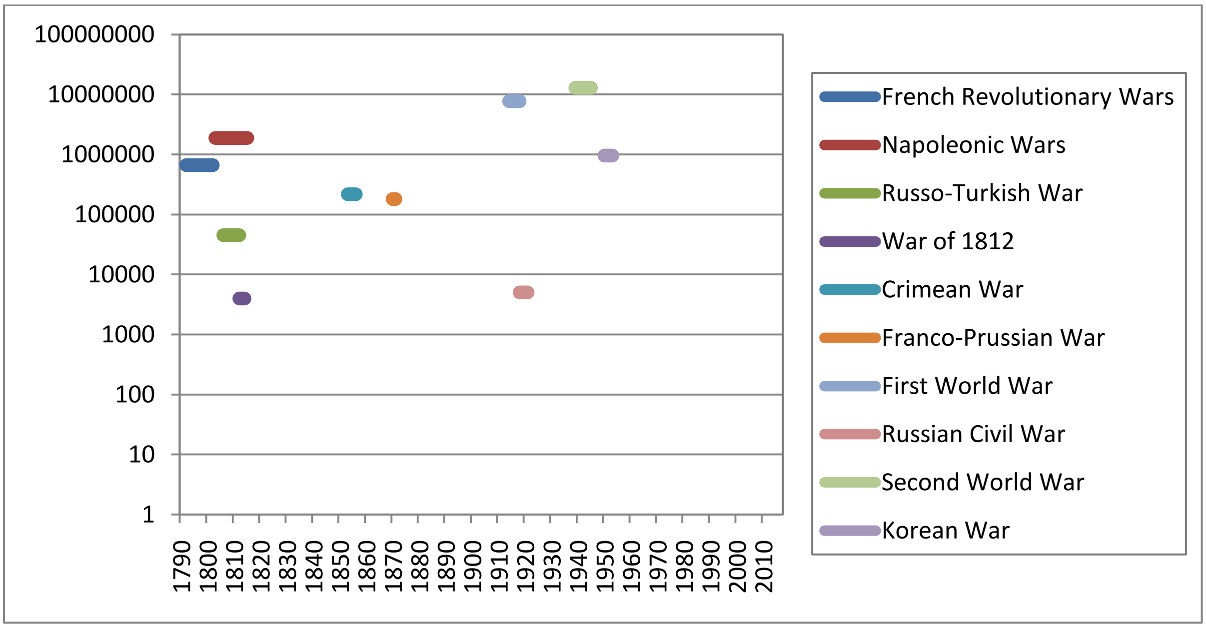


**Figure 3:** Wars, in which the "great power" Great Britain took part and the respective numbers of casualties. (Own depiction, based upon Levy, 1983, pp. 90–91)

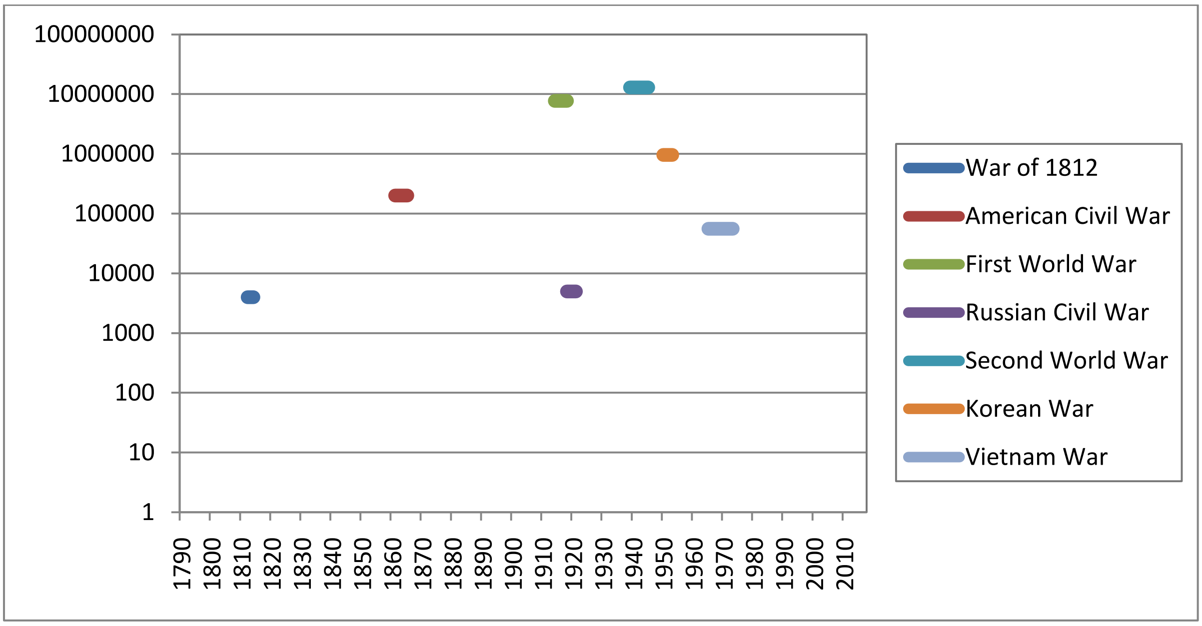


**Figure 4:** Wars, in which the "great power" USA took part and the respective numbers of casualties. (Own depiction, based upon Levy, 1983, pp. 90–91 and Keegan, 2010, p. 477)

However, three wars are added to the chosen wars: the Franco-Prussian War of 1870–1871 with 180,000 casualties (Levy, 1983, p. 91). It is added because it was a major European war with many casualties. However, it is only added to the framework concerning Great Britain, as its effect on the USA should have been limited.

The other two wars affect the USA: the first one is the War of 1812. Levy did not add it to the set of wars affecting the USA, as he did not count the country as a "Great Power" at that time. Furthermore, the American Civil War of 1861–1865 has to be included as well because it was a major conflict verberating the USA and its economy. Regarding casualties, a wide array exists. For example, Reid (2010) writes of "620,000 lives lost" (p. 99). Keegan (2010) mentions 200,000 "soldiers killed in action (own translation)" and "more than one million men lost overall (own translation)" (p. 477), which seems to be a sound estimate. To stay in line with the work of Levy (1983), who looked at casualties from actual fighting, the casualty number of 200,000 as provided by Keegan (2010) is adopted for the American Civil War.

Overall, with few and small changes, the original set by Levy (1983) is adjusted to the requirements of this dissertation and provides a set of major wars with a small amount of arbitrariness in the selection procedure.

The Cold War is not included, as it does not apply to the definition in the narrower sense. It would therefore disturb the homogeneity of the set of wars. As it was a meaningful event, it should nevertheless be kept in mind that it took place 1945–1991. It also had an important effect on the R&D sector (Swedin & Ferro, 2007, p. 111).

### 2.1.4. Technological development according to Nefiodow & Nefiodow

The orthodox Kondratieff cycle covers the technological development over time as well. It is important to check how groundbreaking innovations in the area of weapons technology are related to the general technological reality to understand their interconnection better. Therefore, the scheme of Nefiodow (1990) as well as Nefiodow and Nefiodow (2014) is used. It provides a detailed picture regarding the dating and the rise of different technologies during the time frame covered by this dissertation. Nefiodow and Nefiodow (2014) see Kondratieff cycles as "economic fluctuation with a period of 40 to 60 years (own translation)", which are dependent on so called "basis innovations (own translation)". Another important concept is the one of "leading industries" (pp. 2–4). Nefiodow (1990) defines "basis innovations" as "innovations, which exploit economic new land and trigger a cluster of following innovations (own translation)". Their implementation usually leads to an economic upturn and the countries, which are able to profit the most from using them, become especially powerful (p. 23). According to Nefiodow and Nefiodow (2014), the "leading industries" are the part of the economy, which implements the "basis innovations" (pp. 3–4). Table 1 illustrates the technological reality of the last two centuries. It is interesting to see the chosen countries Great Britain and USA here again as "main profiting countries" during the time frame of this dissertation.

It is interesting to see that the dates regarding the Kondratieff cycles provided by Nefiodow (1990) and Nefiodow and Nefiodow (2014) are close to the ones determined above with the 10-year rolling return of the S&P 500, which are 1842, 1896, 1938, 1974, as well as 2008.

**Table 1:** Technological reality according to Nefiodow (1990) and Nefiodow and Nefiodow (2014). (Own depiction, based upon Nefiodow, 1990, and Nefiodow and Nefiodow, 2014)

| Number | Period | Basis innovations | Leading industries | Main profiting country |
|---|---|---|---|---|
| 1. | 1790–1850 | Steam engine | Textile industry | Great Britain |
| 2. | 1850–1900 | Railway, Bessemer converter | Steel industry | Great Britain |
| 3. | 1900–1939 | Electrical engineering and chemical process technology | Electrical and chemical industry | Germany, United States |
| 4. | 1945–1979 | Automobile | Automobile industry, oil industry | United States, Germany, Soviet Union |
| 5. | 1950s–2000s | Information technology | Industry related to information technology | Japan |

### 2.1.5. Groundbreaking innovations in weapons technology

Already Oparin discussed the problem of how the date of occurrence of "inventions" can be defined when he criticized Kondratieff's work (Garvy, 1943, p. 212). The mentioned problem exists even on a more general level: Jewkes, Sawers and Stillerman (1969), who published on "The sources of invention", discuss problems related to defining them, measuring their meaning as well as determining the person inventing it. The analysis of this area is a decision "… between discussing these matters with concepts that are necessarily somewhat vague and not discussing them at all" (pp. 24–25). The mentioned decision applies to this dissertation as well, which is constructed building upon the work of Mensch (1975), who distinguishes three types of innovations: "basis innovations (own translation)", "improvement innovations (own translation)" and "pseudo-innovations (own translation)" (pp. 54–55, 57). The most important ones are the first named. Mensch (1975) defines them as "the technical event at which the discovered substance or the newly developed procedure is applied for the first time for systematic production or at which a new market is developed for the first time for the new product (own translation)" (p. 134).

#### 2.1.5.1. Critique concerning Mensch's work

Kleinknecht (1990) elaborates the difficulties of this field of research in general and mentions problems related to the appropriate handling of different "innovations", which vary in meaningfulness and also their respective dating. Moreover, the question if the collection of items is sufficiently large arises. Furthermore, the researcher executing the work might be prejudiced; treat different time spans in history differently and may have to work with doubtful material. However, he accepts that certain issues cannot be solved perfectly and assumes that the defects might stay on a limited scale (pp. 83–84, 87). According to Solomou (1986), another important point of critique regarding the general field is that during the last two hundred years, the "factors determining the propensity to innovate" have changed and that therefore, the comparability of innovations is not necessary possible. Related is the rise of the meaning of research and development, which has also changed the field meaningfully ever since the end of the First World War (p. 103).

With regard to Mensch's (1975) work, Clark, Freeman and Soete (1981) criticize two major points: they see the sources used as problematical and the procedure regarding the choice of innovations as arbitrary. Furthermore, they stress the problem of how to treat basis innovations that are closely related (pp. 148–150). Solomou (1986) criticizes Mensch's (1975) sample because it becomes clear only afterwards how meaningful certain "innovations" are. Therefore, he argues that the sample of basis innovations is unknown and accordingly Mensch (1975) presents "an arbitrary selection procedure from an unknown population" (p. 103). Agrell (1990) points towards the same point in the area of "weapons development": he argues that analyzing weapons that became prevalent only might be insufficient to gain a thorough understanding of the area. He suggests looking at unsuccessful cases also (p. 155).

Furthermore, the use of patents for research in the field of innovations can be criticized. Van Duijn (1983) summarizes the critique against utilizing patents as a gauge:

> (1) not all inventions can be patented; (2) for some inventions patents will not be applied for; (3) criteria for issuing patents differ from country to country; (4) not all inventions will become innovations; (5) sometimes a patent is issued after the moment of innovation; (6) patents are often applied for in more countries simultaneously, hampering international comparisons of patent data. (p. 96)

The points made by van Duijn mentioned above are undoubtedly valid. The question is if they are so severe that the use of patents should be rejected right away. In this dissertation, dates regarding patents of groundbreaking innovations in weapons technology are mentioned in cases patents were applied for. However, as can be seen, the dates of the concerning patents are not of major importance, as the new weapons were presented to the public, sold etc. during the same year in most cases.

#### 2.1.5.2. Support for Mensch's findings

Despite all critique, many authors working with different samples provided support for Mensch's (1975) findings over the years. Amongst them are Kleinknecht (1990) and Metz (2006). Kleinknecht (1990) uses a sample constructed by using the data by Mensch, van Duijn (1983) as well as Haustein and Neuwirth and finds that indeed the last two decades of the 19th century as well as the 1930s and 1940s were accompanied by the emergence of innovations, while the first three decades of the 20th century were muted in this regard (pp. 84–89). Metz (2006) finds a similar pattern as Mensch (1975) using an unrelated data set (pp. 97–98). For the sake of completeness it has to be added that Mensch (1975) compares his set to other sets already and finds support for his collection to some extent (pp. 141–144).

#### 2.1.5.3. Set of groundbreaking innovations in weapons technology

Taking the above-mentioned into account, the author of this dissertation considers Mensch's (1975) procedure as solid. The definitions are as clear-cut as possible, even though a certain amount of arbitrariness remains, which is however not avoidable. The general findings by Mensch (1975) are valid, as the mentioned authors with different sets show. Though, learning from the critique suggests adding an unrelated set of groundbreaking innovations in military technology, which another author has defined. Groundbreaking innovations in weapons technology differ to some extent from the basis innovations Mensch (1975) looks at. Also linking them to the first appearance in battle is useless, as it by definition links the first appearance of the innovations to wars. Therefore, a broader range of events is accepted, as long as they regard the first working model of the innovation. Events that qualify are: patents, first working model, presentation to the public, etc. Even though this procedure is much broader than to look at patents only, it is necessary to meet the requirements of this special field of innovations and allows finding the date when they appeared first. Another, more eligible way to do it seems not to be available.

With regard to weapons technology, it seems appropriate to define groundbreaking innovations as innovations, which helped to overcome the recent way of warfare because they provided superiority on the battlefield. They represent in the field of weapons technology what Mensch (1975) defines as "basis innovations" in the field of general innovations. With regard to major innovations in the field of weapons technology in general, van Creveld (1991) mentions the Zündnadelgewehr, tanks, as well as atomic weapons and concludes: "In almost every case the weapons in question were new, and hence caught the enemy materially and – more importantly – psychologically unprepared to resist" (pp. 226–227). It can be concluded that the weapons fitting the definition represent a new paradigm that changes the way of warfare meaningfully and diminishes the meaning of the until-then dominant weapons and tactics. Therefore, for example the airplane in general is included but not jet aircraft, as it belongs to the same groundbreaking innovation and represents rather an improvement innovation in the sense of Mensch (1975). The table below displays the set of groundbreaking innovations in the area of weapons technology of this dissertation that results from the application of the above-given definition on the military materiel of the time frame of this dissertation. The sample is based upon the works of Fuller (1998), Brodie and Brodie (1973), as well as van Creveld (1991).

**Table 2:** Groundbreaking innovations in weapons technology.

| | | | |
|---|---|---|---|
| 1. | Percussion cap | 13. | Automobile |
| 2. | Railway | 14. | Quick-firing artillery |
| 3. | Breech-loading rifle | 15. | Wireless communication |
| 4. | Telegraph | 16. | Submarine |
| 5. | Breech-loading, rifled cannon | 17. | Airplane |
| 6. | Cylindro-conoidal bullet | 18. | Gas |
| 7. | Cartridge case | 19. | Tank |
| 8. | Torpedo | 20. | Radar |
| 9. | Ironclad, screw-driven steamer | 21. | Ballistic missile |
| 10. | Magazine | 22. | Nuclear weapons |
| 11. | Smokeless powder | 23. | Computer |
| 12. | Machine gun | | |

Of Course, the set suffers from similar shortcomings Mensch's (1975) set suffers from. Other researchers might create another list, disagreeing with the presented one. As Clark, Freeman and Soete (1981) write concerning his set: "What are we to make of a list of 20th Century innovations which includes the helicopter but not the aeroplane, which includes the zip-fastener but not nuclear reactors …?" (p. 149).

However, as shown above, the findings Mensch (1975) made building upon his set were nevertheless solid and the same is assumed for the set of this dissertation as well.

#### 2.1.5.4. Full-scale application of the groundbreaking innovations in weapons technology

Regarding full-scale application, efficacy [Wirkmächtigkeit] plays an important role. To measure it, the concept used by Devezas and Santos (2006) is adopted. They look at "modern terrorism" and argue that its rise is comparable to the rise of innovations: during the falling part of the Kondratieff cycle that topped out during the 1970s, meaningful terroristic events occurred and ever since the following trough around the year 2000, the "diffusion phase" takes place, leading to the spreading of terrorism (pp. 245–248). They visualize their findings by showing a sketchy Kondratieff cycle and marking the terroristic acts for illustrating the point regarding the rise of terrorism during the falling part of the Kondratieff cycle. For showing the ensuing spread, they give the number of terroristic acts per year on a timeline. Doing so is a common procedure used by researchers in the field of the Kondratieff cycle. For example, Nefiodow and Nefiodow (2014) use it: to show the efficacy of the "leading industries (own translation)" of the single Kondratieff cycles, they look at "raw-cotton imports by the British textile industry (own translation)" from 1700 to 1800 in pounds for the first Kondratieff cycle, "share of steel with regard to all iron products (own translation)" 1870 to 1950 as a percent of total for the second Kondratieff cycle or "number of in Italy registered cars (own translation)" 1950 to 1990 in million for the fourth Kondratieff cycle (pp. 5–6, 9).

In this dissertation, a comparable procedure is chosen: in the area of small arms and other innovations, production numbers are analyzed. For certain innovations, additional measures are eligible as they display their impact: for example for submarines, the number of sunken tonnage qualifies. However, some caution is advised. Almost automatically, every major war coincides with an explosion in production numbers. Therefore, it is often more important to look at qualitative changes induced by the device under analysis. The torpedo is an example that had profound implications on naval warfare, which were more important than production numbers per se. Regarding the impact of the machine gun, Ellis (1986) notes, "The power of the defence, and particularly the machine gun, had rendered almost nil the chances of successful frontal attack" (p. 124), which means that the prevailing tactics with frontal charges were rendered obsolete instantaneously.

## 2.2. On state, economy, and war

Usually, war increases the "power of the state (own translation)" (Åkerman, 1944, p. 112). This is a valid point especially ever since the Napoleonic Wars, as the French Revolution can be seen as the starting point of modern war. Weller (1966) argues that in "Republican France", all forces of the state were bundled on warfare, which also changed the concept of financing it. Earlier on, armed conflicts were merely "private ventures". Furthermore, it was accompanied by compulsory military service and thereby made a large military force possible (p. 69). To be precise, compulsory military service started in France in 1792–1793 (O'Connell, 1989, p. 174). Also economic measures like price controls came along with the French Revolution. The "Law of the Maximum" applied for a range of commodities (McNeill, 1984, p. 196). The most important items the state dealt with during the First and Second World War in Great Britain and the USA besides financing war were price controls and rationing, wage controls, control of strategically important commodities, as well as the rise of R&D.

### 2.2.1. Economic reflections of major wars

War can disrupt the economy severely. According to von Ciriacy-Wantrup (1936), it can negatively affect "capital goods (own translation)", "consumption goods (own translation)", and human capital. Furthermore, general frictions regarding economic life come along with it. The related fluctuations in prices are outstanding (p. 363). When discussing price movements, Tinbergen and Polak (1950) state that "long waves" are visible, with high points around the years 1810, 1873 as well as 1920 and corresponding low points in 1850, 1896 as well as 1933. They also relate them to major wars: 1810 connected to the Napoleonic Wars, 1873 to the Franco-German War and American Civil War and the one of 1920 to the First World War. They see a causal relationship between wartime inflation and the price peaks of 1810 and the one of 1920, while they are not sure with regard to the one of 1873 (p. 35). Also Åkerman (1944) writes that historically, long-term changes in prices are induced by war (p. 125). On a general level, the economic ramifications of war can be sketched as follows: Ayres (1935) looks at the War of 1812, the American Civil War and the First World War and concludes:

> (1) commodity price inflation, (2) farm prosperity and farm-land speculation, (3) price deflation and a short primary post-war depression, (4) a period of city prosperity and widespread speculation, (5) secondary price deflation and a long secondary post-war depression. (p. 10)

Ayres (1935) explains that major wars are connected to quick major price increases, while the time after the war is accompanied by a long-term and slower decline of prices (p. 3).
However, a qualitative change in the nature of money has occurred during the time frame of this dissertation, which must be kept in mind when discussing prices: Rothbard (2005) writes that the period from 1815 to 1914 was the time of the "Classical Gold Standard" with a system of valutas determined as a defined amount of "gold". With certain deviations, it limited inflation and regulated the "balance of payments". Moreover, it made international economic activity easier (pp. 98–100). Indeed, the 19th century was a time of relative price stability in comparison to what followed afterwards. However, it has to be remarked that this is true with interruptions only. For example, the American Civil War was accompanied by the issuance of "inconvertible Federal notes (greenbacks)" (Silberling, 1943, p. 88). Rothbard (2005) mentions that during the First World War, most countries abandoned the "gold standard", an exception were the USA. The further process towards by and large freely floating fiat currencies as it is ever since March 1973 included various attempts to keep at least a certain link to gold like the "Gold Exchange Standard" from 1926 to 1931 or the "New Gold Exchange Standard" that emerged from Bretton Woods in 1944. Since the relative free float of currencies began, "… the most intense and most sustained bout of peacetime inflation in the history of the world" has occurred (pp. 101–117).

#### 2.2.1.1. The influence of war on prices

Tinbergen and Polak (1950) provide a theoretical explanation of the impact of war on economy and prices, which is summarized below. It is a theoretical foundation regarding the price fluctuations caused by wars. Tinbergen and Polak (1950) argue for a relationship between phases of meaningful inflation and the occurrence of important wars in history. Main problem during belligerent times is the declining availability of the factors of production. Military service reduces the working force and disruptions of maritime trade limit the availability of commodities from abroad. This process is intensified as time passes because the factor labor suffers for example from a limited supply of food; land usually suffers from insufficient treatment including fertilization and capital wears out. Usually, the beginning of war stimulates production, which however quickly reaches the limitations induced from the factors mentioned above. Main task of prices at this stage and afterwards is the distribution of goods, as the stimulus on production is blocked (pp. 137–138). In general, demand varies between

wartime and the after war period, as during the former for example weapons are needed and during the latter among others commodities related to reconstruction (Tinbergen & Polak, 1950, p. 150).
The explanation of the effect of war on prices is divided in four parts; the first one discusses the effects in a closed economy, the second one the quantity of money and the third one looks at an open economy. The fourth part illustrates the mechanism at work in the area of agriculture and mining. Together, they provide a sufficiently comprehensive picture regarding the price movements in a war-torn economy.

#### 2.2.1.2. The influence of war on prices in a closed economy

Tinbergen and Polak (1950) look at supply and demand to judge the influence of war on the "general price level" (pp. 138–139). The limitations regarding supply are mentioned above already. Tinbergen and Polak (1950) write that concerning demand, the most important characteristic is that the state increases its demand and at the same time tries to lower private demand by imposing taxes, limiting investment by private companies and shaping incentives for saving to decrease the amount of private consumption. However, a net increase in demand usually occurs. Earlier on not used resources have a small mitigating effect only. The factor enabling increased demand by the state through reducing private demand is the increase in prices. The increase in total demand caused by augmented government demand leads to a price increase, which lowers the purchasing power of the part of the population receiving a little flexible amount of income. Entrepreneurs should by and large profit from the situation and experience rising incomes, which however usually are taxed and saved rather then used for consumption. For a while, some kind of equilibrium is created. However, usually wage increases are demanded after a while, which leads to renewed price increases and an upward spiral starts. The mechanism fueling inflation is dependent on "net additional government demand", which is the new demand of the state minus the private demand that did not take place because of the factors mentioned above like the implementation of taxes. The mechanism is further dependent on the velocity and extent wages increase, the amount of saving by entrepreneurs as well as the design of the tax system (pp. 139–143).
Regarding the velocity of price increases, Tinbergen and Polak (1950) argue that it usually accelerates as time passes. The above-mentioned process of wage increases tends to happen quicker and quicker after new increases in the general price level as workers tend not to accept cuts in purchasing power over longer periods of time. Furthermore, demand is not only augmented by "net additional government demand"

but over time hoarding by producers as well as consumers sets in as they react to ever increasing prices. The process can finally go so far that the speed of price increases approximates almost infinity. Historical examples are the German hyperinflation of the Weimar Republic or the one that occurred in Greece after the Second World War (pp. 144–145).

#### 2.2.1.3. The influence of the quantity of money

Concerning the quantity of money, Tinbergen and Polak (1950) state that it of course plays a role, even though they see the development described above as the core point of inflation. However, usually actual money printing or increasing the amount of debt of the state is used for financing a part of the expenditure. Therefore, a considerable but not linear interrelationship between the quantity of money and the speed of price increases as well as the general price level exists (pp. 145–146).

#### 2.2.1.4. The influence of war on prices in an open economy

Tinbergen and Polak (1950) mention the possibility to buy goods from abroad as the main difference to a closed economy. They might be purchasable on credit or by using the reserves of gold or foreign exchange the country in focus has. The other important factor in contrast to a closed economy is the exchange rate of its currency. A rising amount of imports in the early phase helps to satisfy demand and moderate inflation. Another usual process is the expectation of further rising prices and devaluation of the currency and this might lead to a "flight of capital". Fixed exchange rates usually deplete the foreign exchange reserves over time and also might the state become unwilling to sustain its own currency. The solution to this problem is allowing a freely floating currency. After a period of inflation, this is usually associated with a declining exchange rate. During regular times, this should lead to a rebalancing of the trade balance as well as the exchange rate of the currency. However, the described process might not work during inflationary times. The elasticity regarding demand from abroad for domestic goods and also the elasticity concerning domestic demand for foreign goods might be insufficient to restore equilibrium. Moreover, the depreciation of the exchange rate might proceed over time and a flight of capital can worsen the situation even more (pp. 148–151).

#### 2.2.1.5. The influence of war on the production of commodities

Another important component of the effect of war on prices and the economy is what happens in the sector of commodities production. Additionally, the natural resource sector is heavily affected by the price declines of the after-war period. For example Abel (1978) and von Ciriacy-Wantrup (1936) provide detailed historic descriptions of agricultural crises during the period covered by this dissertation. Silberling (1943) explains the general mechanism for the agriculture and mining business as follows: the increase in demand occurring during the war meets an inelastic supply. Increasing agricultural supply takes time, depending on the crop up to several years. Also in the mining industry, it takes time to increase production; possibly it is dependent on exploration, which is connected to uncertainty. However, as the war goes on, an increase in supply takes place. Also borrowing by farmers gets attractive to respond to higher prices, which possibly leads to insolvency in the years of declining prices after the war, as falling prices of their products make servicing the debt difficult. A comparable situation occurs usually in the mining business as rising prices make extending supply attractive. The falling demand caused by the end of the war in combination with rising supply by among others “scrap metal” or “war surpluses” lead to falling prices and similar problems as in the agricultural sector (pp. 59–63).

#### 2.2.2. State interventions

State interventions were heavy during the time frame of this dissertation. Von Ciriacy-Wantrup (1936) provides an interesting overview regarding the financing of the major wars of the period 1790 to 1920 (pp. 301–360). For the sake of brevity and clarity, the focus below is on the two World Wars. The explanations provide an overview and better understanding in general. Furthermore, they help to understand the rise of the R&D sector in the right context. The rise of the R&D sector in turn was a meaningful development regarding the emergence of innovations, military and general ones alike.

##### 2.2.2.1. Financing war

Pollard (1976) describes how the First World War was financed in Great Britain: loans played a meaningful role, increasing from GBP 362 million for the “fiscal year 1914–15” to GBP 2,500 million four years later. The overall amount of loans for the period from the beginning of the war until early 1919 amounted to GBP 8,742 million. However, also various “taxes” were increased meaningfully and new ones introduced like the “Excess Profits Duty”, which superseded the “Munitions Levy”. Both were intended to tax profits related to war demand (pp. 63–64). Also, the amount of “legal tender money” almost doubled during the war (Pollard, 1976, p. 69). The situation in Great Britain during the Second World War was comparable. According to Pollard (1976), the state was ready for steering a war economy (p. 297). Broadberry and

Howlett (2000) describe that for financing the war, taxes were increased, and especially loans played a meaningful role. Funds from citizens were channeled into the hands of the government by offering special products and also by limiting the supply of competing products (pp. 48–51). However, also "lend-lease" played a meaningful role to enable Great Britain fighting the Second World War (Broadberry & Howlett, 2000, pp. 52–53). The USA entered the First World War in 1917 only, which means this case of war finance provides little new. Concerning the situation during the Second World War in the USA, Rockoff (2000) describes that the government expenditure during the period 1942 to 1945 was financed to 47% by "taxes", 27% "borrowing from the public", 20% "money created by the banking system", and 6% "government-created money" (p. 108).

#### 2.2.2.2. Price controls and rationing

In general, price controls might date back as early as to the Roman Republic (Herz, 1988, pp. 38–39). They were used at times ever since but especially during the Second World War on a large scale.

Pollard (1976) writes that the state of Great Britain started purchasing foodstuffs like "sugar" and "meat", but also "flax" and other fibers during the early phase of the First World War but by and large, state interventions were not intended on a large scale in the beginning (pp. 42–43). Even though some rationing of foodstuffs took place on a regional level and endured for some time after the war, a general "rationing scheme" for the whole country existed only for "sugar" (Pollard, 1976, p. 52). As the war proceeded, further measures were implemented by the state, Pollard (1976) mentions amongst others: command of private companies by different measures, control of foreign trade, to some extent price controls, as well as command regarding human capital (p. 47). The situation culminated as follows:

> By the end of the war, the Government had direct charge of shipping, railway and canal transport; it purchased 90% of all the imports and marketed over 80% of the food consumed at home, besides controlling most of the prices. Direct or indirect control over industry and agriculture was virtually all pervasive.
> (Pollard, 1976, p. 47)

Concerning the situation in Great Britain during the Second World War, the following applies: Zinn (1978) writes that even though plans regarding interventions into the economy for the case of war were available, they were not implemented. Rather, taxes were increased and bonds issued during the early phase of the war, which was accompanied by relatively meaningless price controls. However, the heavy inflation and difficult supply situation in 1941 paved the way for stronger regulations of the economy that were effective since 1942 and included “rationing (own translation)” and subsidizing of certain foodstuffs. The “‘utility scheme’” and the “‘Goods and Services (Price Control) Act’” in combination meant heavy interventions into the process of production with regard to what was produced, in what quantity and with the use of how many resources and to what maximum price. To some extent, inefficient producers were even forced out of production. The system also applied to second-hand articles and “services (own translation)”. Ever since 1942, this system was sufficient to control prices during the Second World War (pp. 30–36, 38–39). It remained unchanged after the war and the last “price controls (own translation)” were abolished in 1958 only (Zinn, 1978, pp. 69, 72–76). Between 1966 and 1970, they were reintroduced and again in the early 1970s, when also wage controls were implemented until 1977 (Zinn, 1978, pp. 82, 88).

Regarding the USA, Zinn (1978) explains that the country only overcame the Great Depression through the economic upswing induced by the Second World War. Until late 1941, “tax increases (own translation)” were the means of choice to fight inflationary pressures. However, increasingly rising prices and “wages (own translation)” led to the implementation of stricter interventions. The foundation of the “‘Office of Price Administration’” followed as well as the “‘Emergency Price Control Act’”, which served as legal fundament for the interventions. Prices were capped in 1942 with the “‘General Maximum Price Regulation’”; to some extent, it did not apply to the agricultural sector. The price increases proceeded and were finally under control in 1943 after Roosevelt’s “‘hold-the-line-order’”, which augmented wage controls, increased price interventions in the agricultural sector and broadened the amount of foodstuffs under the system of “rationing (own translation)” (pp. 50–58). However, a meaningful “black market” developed over time (Rockoff, 2000, p. 87). All “price controls (own translation)” were abolished in the USA in 1946 but during the Korean War, the measures were implemented again (Zinn, 1978, pp. 69–70). The same applies for the period between 1971 and 1973 (Zinn, 1978, pp. 81–82).

#### 2.2.2.3. Wage controls and changes regarding labor

Pollard (1976) explains that in Great Britain, the First World War was accompanied by the substitution of men by women in certain parts of the economy and also by disproportionately rising wages for unqualified workers (pp. 77–78, 86). Furthermore, certain struggles occurred regarding wage increases (Pollard, 1976, pp. 79–87).

According to Zinn (1978), Great Britain did not implement any wage controls during the Second World War, even though wage controls and price controls are usually used in combination during belligerent times. However, the state drafted civilians for duty at an even larger scale than Germany at that time. Also were "labor conflicts (own translation)" strictly regulated (pp. 36–37, 45). Even though the legal framework for commanding human capital existed and some instances of strong interventions took place, it was tried to intervene as little as possible (Pollard, 1976, p. 305). However, during the four years following the summer of 1939, 8.5 million people were activated "for the Forces, the auxiliary Forces, and the munitions industries, …" and the year 1941 even brought the "conscription of women" (Pollard, 1976, p. 306).
Concerning the USA, Zinn (1978) writes that in late 1941, an agreement was made to avoid labor conflicts during the war in the sense of a party truce. During the next calendar year, with the "'Stabilization Degree'", wage controls were put in force that capped wage increases by and large to 15%. However, this affected workers negatively and led to labor conflicts during the ensuing time (pp. 57, 63–66). In general, the Second World War came along with economic prosperity in the USA. Rockoff (2000) describes that a meaningful amount of people joined the workforce during the war years; this applies not only for male workers but for female ones also (pp. 100–103).

**2.2.2.4. Commodities of strategic importance**

Silberling (1943) writes that during the Second World War, rationing and planning regarding the distribution and use of commodities important for warfare took place on an unprecedented scale. Regarding the USA, the "Army and Navy Munitions Board" categorized "'strategically important'" as well as "'critical materials'" in early 1940 for which rigorous control concerning distribution and use was considered due. The first group contained for example "rubber" and "manganese ore", the second one among others "phenol" and "toluol". The development of materials capable of substituting others, which were scarce or not available at all, occurred also on an unprecedented scale (pp. 60–61).

**2.2.2.5. Totalization of war and the rise of R&D**

Ellis (1986) describes that the American Civil War was the first modern, totalized war regarding the factors mobilization of men, forces of production, as well as the goal of annihilating the maximum amount of enemy soldiers as possible (p. 174).

A related phenomenon is the rise of the R&D sector. The state pushed directed research in the economy to some extent already during the First World War. Pollard (1976) writes that in Great Britain, the "Department of Scientific and Industrial Research" dates back to 1915 (p. 54). The requirements of the war economy led also to the implementation of practices related to administration and bookkeeping that were not used before (Pollard, 1976, pp. 54–55). The kick-off for the rise of research and development in general can be seen as closely tied to war, as the increase in expenditure for research and development in Great Britain from 1928 to 1958 illustrates: from 0.1% of GNP to 1%, while a meaningful acceleration took place since 1935 when Germany's military power became more obvious (Solomou, 1986, p. 103). Regarding the USA, Brauch (1990) writes that the spending hovered around USD 4,000,000 before 1935 and amounted to USD 513,000,000 in 1945, not including the costs of the "Manhattan Project". The development of strongly rising spending proceeded after the Second World War until the late 1980s (p. 179). A good example for research and development activities related to the military after the Second World War is what happened in the USA. Brodie and Brodie (1973) describe that the air force wanted to keep the research structures that proved successful during the war. Initially in cooperation with a company producing airplanes, "Project RAND" became an autonomous think tank over time. The army and navy had comparable programs (pp. 270–271). "Military R&D" might have accounted for about one third of "the 1980 global R&D budget" (Thee, 1990, p. 106). Furthermore, it can be seen as a major factor driving the "arms race" (Thee, 1990, p. 119).

The "Manhattan Project" started in August 1942 (Powaski, 1987, p. 6) and on 16$^{th}$ July 1945 the explosion of "the first atomic bomb" took place (Powaski, 1987, p. 22). Jungk (1982) describes that the effort included the expenditure of USD 2,000,000,000 as well as employing a personnel of 150,000 over an extended period of time (p. 165).

### 2.2.3. General innovations, military innovations, and their cohesion

First of all, it is interesting to see how general innovations and military innovations have emerged during the last two centuries. Regarding the field of general inventions, Jewkes, Sawers and Stillerman (1969) mention that by and large they were the product of single persons during the century ending in 1900, while during the following century the output came from "research laboratories" (p. 37). However, the output comes from different organizations: "research organization of the industrial corporation, the industrial research association of a whole industry, the specialized institution (profit or non-profit seeking) and the government research laboratory" (Jewkes, Sawers & Stillerman, 1969, p. 104).

According to Dupuy (1990), also in the area of weapons technology, single persons came up with innovations until the 19th century. Especially since the second half of the 19th century, a change occurred as directed research arose and civil technological innovations related to the "Industrial Revolution" found application in military affairs as well (p. 299). The usual process until the 20th century, Dupuy (1990) opines, was that changes in general technology made solving an existing problem in the field of weapons technology possible, which someone eventually did. State-induced research in the field of weapons technology is a phenomenon that arose during the First World War only (p. 300).

Kaldor (1982) describes the interconnection between "innovations" in the area of general technological development and the one in the area of the military: around the end of the 19th century, important innovations arose from the military industry that also played a role in the civilian sector afterwards. She mentions the "assembly line", which originates from the production of "small arms", improvements in steel production originating from the production of "armour plate" as well as the "turbine engine", which was in the beginning quickly adopted for use in military ships. She opines further that the production of airplanes and cars in Great Britain originated from military companies. Regarding the USA, she argues that the production of "firearms" can be seen as the fundament for the "techniques of mass production and the concomitant development of the American machine-tool industry". Also a large part of the electronic industry in the USA emerged from a similar background (pp. 39–41, 55). One example is the production of Colt "revolvers", where an impressive level of "standardization" and interchangeability of parts was reached (Pauly, 2004, p. 89). Arms producer Remington might have been one of the first to use some kind of assembly line (Brodie & Brodie, 1973, p. 133). Furthermore, Kaldor (1987) introduces the concepts of "'spin-in'" and "'spin-off'". "'Spin-in'" means general innovations find their way towards the technological reality of the military, in the case of "'spin-off'", it is the other way round (pp. 149–152).

Finally, an interesting general contribution to the relationship between military innovations and ones in the field of general technology is the following: Perez (2005) writes that a certain absence of economic constraints in the field of "war-related expenditure" enables R&D projects that include not only costs that would not be accepted in a market-driven process but also leaving the recent technological reality looking for solutions in remote fields. Later on, the results can find their way back into the general technological reality (pp. 28–29).

### 2.2.4. The influence of war on military technology

Already Heraclitus saw war as the creator of everything (Von Ciriacy-Wantrup, 1936, p. 7). This is perhaps an overstatement but contains some truth. Focusing on the influence on weapons technology, it must be assumed that war has a stimulating effect. The hardship of battle and war should have inspired man from the beginning to search for superior weapons to win and bring the war to an end. This view is shared by Fuller (1998), who wrote "Tools, or weapons, if only the right ones can be discovered, form 99 per cent. [sic!] of victory" (pp. V, 30). Shields (1954) provides an example: he mentions the stimulating effect the American Civil War had on the evolution of the modern cartridge and that war usually has such an effect (p. 97). The precise effect is difficult to determine, however. It must be assumed that the strength of the influence varied over time. Similarly undetermined is Fuller's (1998) "law" that steered the "evolution of weapons" over time: "… those who adapt themselves the more rapidly and perfectly to material, intellectual, moral and physical changes, more readily survive" (p. 32).

### 2.2.5. The reciprocity between war and general innovations

Even though difficult to measure, a certain relationship between war and general innovations should exist. Concerning the influence of war on general innovations, the somewhat trite example of food conservation is interesting. According to Weck (no date), Napoleon offered a considerable sum of money for a usable treatment. Appert received the price in 1810 for his procedure. He treated food with heat and stored it in glass vessels (p. 3). This case might look unimportant but it solved an essential problem. It is interesting to see that Perez (2005) mentions "canned and bottled food" as one of the main elements of the wave of technology starting in 1875 (p. 14).

Concerning the influence of general innovations on war, it is clear that the field of general innovations enables the production of better weapons. A historic example is the superiority of weapons made of iron relative to ones made of bronze (Rixner & Wegner, 1973, p. 42). In fact, almost all general innovations made fighting a war easier and to some extent more destructive. Examples are the railway for the mobilization of troops, steel as a superior material than iron or advances in chemistry for the more efficient production of more powerful explosives.

## 2.3. Literature related to the Kondratieff cycle

The two most important fields of literature related to the Kondratieff cycle for this dissertation are the ones that deal with war and technology. The former field stresses the interconnection of elements of the orthodox Kondratieff cycle like war and economic development and prices, while the latter provides hints regarding the question when innovations arise with regard to the Kondratieff cycle.

### 2.3.1. Literature related to the Kondratieff cycle and war

The literature related to the Kondratieff cycle and war in the narrower sense is already relatively old. Goldstein (1988) defines four major groups of literature concerning the Kondratieff cycle during the early decades. One of them is the "war theory", which sees the cyclic occurrence of wars as the reason for the Kondratieff cycle. The "war theory" lost its importance in the decades after the Second World War, however (pp. 23–25).

Goldstein (1988) mentions the following authors who belong to the "war theory": Åkerman, Rose, Bernstein, Silberling, Tinbergen and Polak, von Ciriacy-Wantrup, Dickinson, as well as Imbert (pp. 32–39). The central statements of the authors of this group are relatively similar. Therefore, only the most important authors and insights are summarized below. A figure by Åkerman (1932) is the starting point, which clarifies one of the core theses of the "war theory": the close relationship between war and price increases. Dickinson's (1934, 1940) comments on prices, the economy, and war follow. Afterwards, the main contributions by Bernstein (1940) follow. He focuses on the impact of war on the economy. Outstanding is von Ciriacy-Wantrup (1936), who explains the Kondratieff cycle extensively and presents empirical evidence. His remarks regarding agricultural crises, the interconnection between the long wave and war, as well as the cyclic occurrence of major wars is outstanding. Finally, the brief contribution by Rose (1940) follows, who combines the "war theory" with technology already. Useful contributions by Tinbergen and Polak as well as Silberling were summarized above already. As Åkerman and Imbert do not provide further insights, their work is not discussed below. However, Åkerman (1932) provides an interesting figure, which is the most interesting of the whole "war theory". It is reprinted below and shows the price level in Great Britain (thin line) and the USA (thick line).

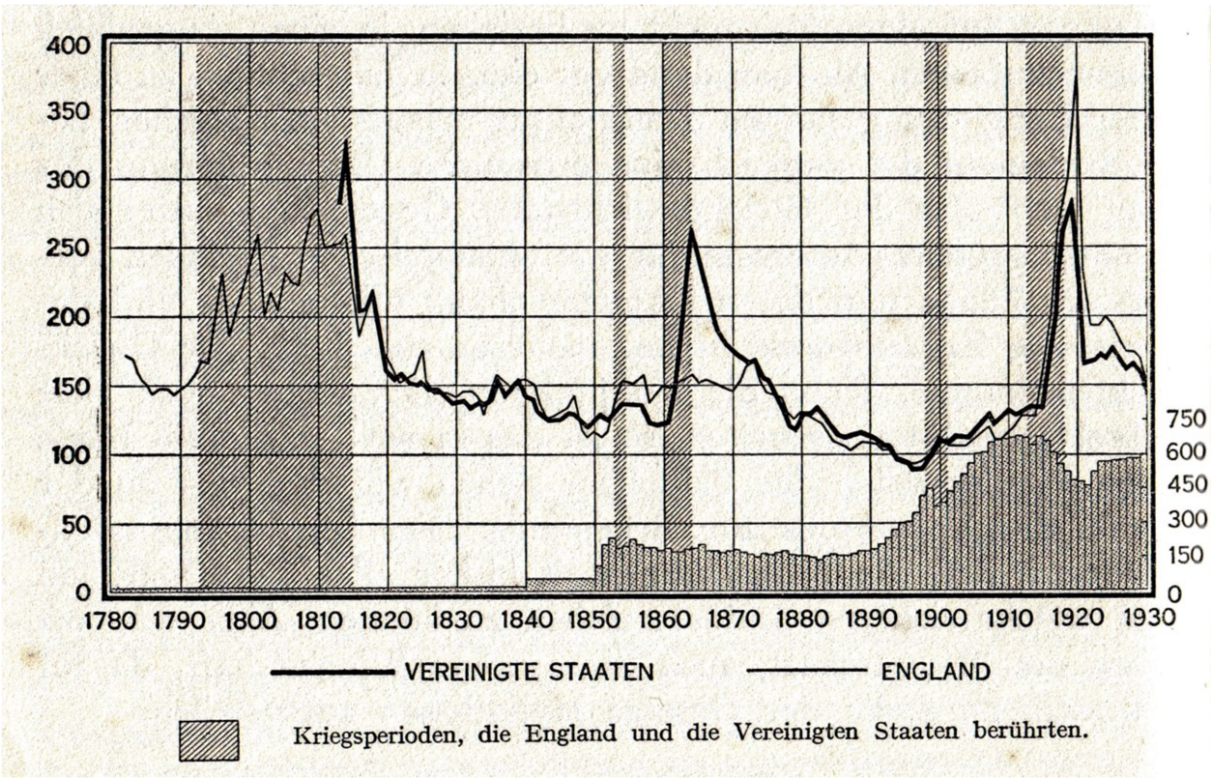


**Figure 5**: "Long waves in prices (own translation)". (Åkerman, 1932, p. 56. Reprinted by kind permission from Springer Nature)

Furthermore, war periods for both countries are marked with shaded areas and global gold production is depicted with the bars. The monetarists' theory for explaining the long wave can be seen as related to the "war theory" (Goldstein, 1988, p. 36). The figure provides a better understanding of the sudden and heavy price increases during times of war and the rather drawn-out price decreases in the decades afterwards. Overall, it summarizes the main message of the "war theory".

**2.3.1.1. Frank G. Dickinson**

Dickinson (1934) looks at the Warren & Pearson index of wholesale prices and concludes that major wars caused severe price spikes in 1814, 1864, as well as 1920. Decisive troughs were reached in 1843 and 1896–1897 (pp. 166–167). It is interesting that the low points in 1843 and 1896–1897 are more or less identical with the lows of the 10-year rolling return of the S&P 500 used in this dissertation that took place in 1842 and 1896. Moreover, Dickinson (1934) discusses war as the reason for economic crises in the after-war period. Usually, a brief crisis occurs directly after the war and is accompanied by price declines. The demand that did not take place during the war leads to an ensuing economic upswing, which ends the brief after-war crisis. Later on,

further falling prices lead to renewed problems in many sectors of the economy, however (pp. 171–173).
Dickinson (1940) presents five reasons for the existence of a Kondratieff cycle that started in the last decade of the 19th century: His first reason are the price peaks in wholesale prices of the years 1815, 1865, as well as 1920. His second argument is based upon the work of Thorp and Mitchell, who worked on Kondratieff's finding that the upswing of the long wave is usually accompanied by economically more prosperous times than the downswing. The work of authors like Kondratieff and von Ciriacy-Wantrup is his third pillar of support. His fourth point is the occurrence of unemployment, misery, and social unrest during the falling part of the Kondratieff cycle. The fifth point is that the volume of production in the USA peaked out in 1917 (pp. 330–331). Overall, he sees war as the reason for the Kondratieff cycle (Dickinson, 1940, pp. 334–335).

#### 2.3.1.2. E. M. Bernstein

Bernstein (1940) argues for a heavy impact of war on the economy, which applies also to countries not involved into the hostilities. Usually, economically difficult times come along with the beginning of a major war that get more serious in the early phase. Afterwards, a boom in the armaments industry follows and usually also the general economic situation improves meaningfully. However, the scope of the economic upswing is limited by the usually following shortages concerning the factors of production (pp. 525–526).
According to Bernstein (1940), the situation in countries not involved into the war is affected by opposing factors. The most important positive factors might be the purchases of armaments and general goods by the countries at war as well as the fabrication of things in neutral countries that were usually bought in countries now at war that are not available any more. The most important negative factors are the possible unavailability of commodities necessary for production from other countries as well as the interruption of trade caused by the war. Usually, the mentioned negative factors become more meaningful as time passes (pp. 528–530).
The events after the war are as follows: Bernstein (1940) explains that usually an economic crisis occurs in the countries that were involved into the war and the neutrals that exported to the former. The reason for the crisis is the end of the war-related demand. Soon, the economic situation improves again as demand that did not take place during the war occurs as well as demand related to reconstruction. The countries that lost the war may suffer from a longer crisis, however (pp. 530–532).

Bernstein (1940) explains that the design of the "monetary system" shapes the longer-term economic situation after the war. Accepting the devaluation of the currency that took place during the war even after the war is usually beneficial for the economy, while countries trying to reestablish the pre-war exchange rate may experience a longer period of economically difficult times. Usually, also the attempt to return to the gold standard in the after-war period as well as the still elevated level of interest rates dampens economic development. Further problems arise in the area of agriculture, where oversupply is perhaps the most urgent problem after the war. Moreover, general adjustments take place when the normalization of trade occurs (pp. 532–534).

Regarding the relationship between the Kondratieff cycle and war, Bernstein (1940) concludes that war has a meaningful impact on prices and interest rates and might be the factor that accounts for the upper turning point of the Kondratieff cycle. It plays a meaningful role regarding the longer-term depression after the war caused by monetary difficulties as well (p. 535).

#### 2.3.1.3. Siegfried von Ciriacy-Wantrup

Von Ciriacy-Wantrup (1936) summarizes the scientific discussion at the time of writing and concludes that none of the major authors in the field of the Kondratieff cycle has proven the existence of the cycles. No one has suggested a solid theory, either. The list of authors he mentions includes amongst others van Gelderen, Kondratieff, as well as Åkerman. He argues against statistical methods as they only manipulate the data and produce results that do not exist in the raw data. Furthermore, he discounts the use of the index used by Kondratieff regarding agricultural goods as it contains elements like "silk (own translation)" that do not play a role for the economy of Great Britain. Nevertheless, he constructs his own indices and his results are by and large similar to the ones by Kondratieff (pp. 17–19, 376–379).

##### 2.3.1.3.1. Agricultural crises

A meaningful contribution by von Ciriacy-Wantrup (1936) is his extensive discussion of the agricultural crises of the time frame 1790 to 1930. He distinguishes three major crises, the first one is "the agricultural crisis after the Napoleonic Wars (own translation)" that started about in 1814. The second one is "the agricultural crisis of the last quarter of the 19$^{th}$ century (own translation)"; its starting date is about 1875. The last one is the "agricultural crisis after the Great War (own translation)" that began approximatively in 1920 (pp. 17–102, 103–175, 176–254). Apparently, the major crises he discusses are related to meaningful wars, as his classification suggests. His empirical remarks add interesting details because long-term movements of prices are a meaningful part of the Kondratieff cycle.

The conclusion von Ciriacy-Wantrup (1936) draws from the three crises is the following: main driver of agricultural crises are falling prices for agricultural products. Even though other prices fall during times of crisis as well, the dependency on fixed costs for production brings the agricultural sector into an unfavorable situation. As farmers usually do not have an alternative, production cuts do not occur. Therefore, the price declines go on over time. Moreover, servicing debt becomes increasingly difficult as prices fall (pp. 254–257).

**2.3.1.3.2. The long wave**

In the second part of his work, von Ciriacy-Wantrup (1936) deals with the long wave, which he splits into two parts: "Aufschwungspanne [upswing]" and "Stockungsspanne [downswing]". He opines that the long waves are not endogenously rooted in the economic process but are the effect of exogenous "changes in data (own translation)", mostly induced by wars. He argues against looking at wars as exogenous shocks, as they occur too often and are too meaningful to leave them aside when explaining economic development. He summarizes the impact as follows:

> Wars have always had important, direct consequences on the economy – destruction of human lives, of consumer goods and capital goods, as well as turmoil in the production of consumer goods and the births of humans and so forth – and indirect consequences – dislocation of production, expansion and restriction of markets, changes regarding technology, changes of the opinion of people concerning international trade and so on. Apart from the mentioned consequences, the impact of war on wages and prices became apparent during the analyzed time frame, which also happened earlier already, however.
> (own translation, pp. 361–363).

Von Ciriacy-Wantrup (1936) looks at wars, the production of gold, the occurrence of technological innovations, and the "expansion of markets (own translation)" and considers the mechanism of their impact on the economy as by and large similar. However, the impact of war itself is by far the greatest: the power of the state is meaningful regarding money and credit and the demand for war goods is large and not subject to the law of supply and demand. Demand comes to an end when the war is over only, which triggers a crisis of an enormous size.

Usually, credit is used in the economy to invest in productive capital. War goods by contrast are not productive but destructive. After the war, this becomes a problem. At times, there is no other possibility for states than to default on obligations, which comes along with turmoil in the economy. Heavy taxes that are needed to support the states in a financially difficult position have further dampening effects on the economies of the mentioned countries. He even argues that to a meaningful extent, war has an impact on the other above-mentioned factors production of gold, the occurrence of technological innovations, and the “expansion of markets (own translation)” (pp. 364–366).

#### 2.3.1.3.3. The cyclic occurrence of wars

Furthermore, von Ciriacy-Wantrup (1936) discusses the possibility of a cyclic occurrence of wars. He looks at the wars of the time frame of his analysis and argues for 32 years of peace after the major wars: 1816 to 1847 and 1872 to 1903. The belligerent phases took 24 years twice: 1792 to 1815 and 1848 to 1871. The phase 1904 to 1918 took 15 years.

When he looks for possible explanations, he rejects the “succession of generations (own translation)” in the narrower sense. Rather, he accepts that humans are influenced to an extraordinary degree during certain periods of their lives and thinks especially of the soldiers participating in the wars. They experience the hardship of war in every aspect and should by and large try to keep peace afterwards, which should limit the probability of the outbreak of another meaningful war together with the lasting economic consequences of the preceding belligerent period. In accordance with the “‘laws’ of Eilert-Sundt’s cycle (own translation)”, von Ciriacy-Wantrup observes years with extraordinary years regarding the birth of humans after the phases of major wars. When they grow up and reach an age ready for working and fighting after about 25 years, they also get political influence, while the older generations that kept the peace before retire. Overall, the probability for another major war has increased meaningfully after two to three decades (pp. 366, 370–373).

The reason for the temporal limitation of war periods is their heavy consumption of resources of all kind, which makes warfare more and more difficult as the war goes on (von Ciriacy-Wantrup, 1936, pp. 373–374).

#### 2.3.1.4. Albert Rose

Rose (1941) argues for a close relationship between the Kondratieff cycle, technology, and war. He opines that the time before a major war is an economically good one. Moreover, the time after a major war is also an economically prosperous one as demand that did not take place before has the opportunity to do so now. Furthermore, the necessity for reconstruction after the war fuels the economy. The end of the mentioned factors of demand brings economically difficult times during the late stages of the Kondratieff cycle, which are the time of the rise of innovations that fuel the next cycle in turn (pp. 105–106).

He even states that "… modern war may be *the innovation* par excellence in the Schumpeterian system, and as such, the dominant cause of long waves in economic activity" (Rose, 1940, p. 105; as cited in Goldstein, 1988, p. 33). Rose (1941) explicitly mentions the role of innovations in the field of the military and sees the aircraft as a conditio sine qua non for the Second World War. Without the two World Wars, the aircraft might have been the most important innovation for the next Kondratieff cycle. However, he concludes that the two World Wars have ended Schumpeter's framework [of the Kondratieff cycle] that the Industrial Revolution started (pp. 105–106).

### 2.3.2. Literature related to the Kondratieff cycle and technology

Brief explanations regarding the work of Kondratieff follow below as well as contributions by Schumpeter, Mensch, and Perez. They worked especially in the field of technology related to the Kondratieff cycle. The most important contribution by the mentioned authors regards the question during which stage of the Kondratieff cycle inventions/ innovations occur.

#### 2.3.2.1. Nikolai Kondratieff

Chapter 2.1.2.2. above provides an overview regarding the work of Kondratieff and the critique it provoked. His statement that inventions are usually made during the falling part of the wave but reach a state of broad implementation only during the next rising wave can be seen as a starting point for the discussion how general innovations emerge and how they are related to economic growth.

#### 2.3.2.2. Joseph Schumpeter

Goldstein (1988) argues that the early discussion regarding the Kondratieff cycle related to the "innovation theory" was tied to Schumpeter. "Clusters of innovations" cause the Kondratieff cycle and prosperity in certain parts of the economy. Usually, the parts of the economy affected are related to a specific technology in each cycle (pp. 23–24).

Schumpeter's main contribution to the topic of the Kondratieff cycle is his book "Business Cycles", which appeared in 1939 and therefore during the early years of the discussion related to the Kondratieff cycle. Schumpeter (2008) describes the three at that time identified Kondratieff cycles as well as the corresponding dates: the first one covered "the industrial revolution (own translation)" and ranged from 1787 to 1842. The second one took place between 1842 and 1897 and covers "the time of steam and steel (own translation)" or the "railway (own translation)" and the third one covers the period from 1898 to the time of writing [1939] and was the one of "electricity, chemistry and of the motor (own translation)" (pp. 180, 263, 409). Schumpeter (2008) writes that the "innovations (own translation)" only get as meaningful as they eventually usually are because they also influence the economic reality. Additionally, they tend to develop further over time  (p. 177). Schumpeter (2008) also stresses the fact of their longevity in the sense that they are important to the economy even after the end of the Kondratieff cycle that was dominated by them (p. 315). Noteworthy are his findings when he looks at the development of new technologies during the late phase of a Kondratieff cycle: by reference to the historical economic development in Germany, he mentions the increasing importance of "railways (own translation)" during the last two decades of the first Kondratieff cycle; a similar development occurred with the "chemical and electric industry (own translation)" during the late phase of the second one and eventually, the mentioned sectors were the pillars of the following one (Schumpeter, 2008, p. 371). Overall, Schumpeter provides historical evidence regarding the emergence of innovations late during a Kondratieff cycle that play a meaningful role during the next one regarding economic development.

#### 2.3.2.3. Gerhard Mensch

Mensch (1975) argues that the "technological stalemate (own translation)" occurs when the up to then paradigm of production suffers from a declining marginal utility of the factors of production labor and capital. The "basis innovations (own translation)", which appear, tend to show up in clusters and lead the new upswing. The problem however is that ways of implementing them are not readily available when the old paradigm comes into crisis, which usually causes a depression. He defines "basis innovations (own translation)" as a new "technology (own translation)" or way of production, which is able to employ a considerable workforce (pp. 14–15, 19, 36, 54). Mensch (1975) suggests the "metamorphosis model (own translation)", the advantage of it is that it shows the single s-shaped cycles, which are not visible in the wave-shaped one as suggested by Kondratieff and others. Furthermore, the meaning of "stagnation (own translation)" as the force, which drives the model, is stressed (pp. 84–85). However, the concept of "S-shaped" models is not an original contribution of

Mensch but much older already (van Duijn, 1983, pp. 20–44). The historic phases of clustering of innovations took place around the years 1825, 1886 and 1935 (Mensch, 1975, p. 25). The decisive difference of Mensch's work with regard to the one of other authors is the time when the innovations of the next Kondratieff cycle occur: he argues that they occur in the trough before a new upswing of the Kondratieff cycle (Perez, 1983, p. 364). The reason is according to Mensch (1975) that they are needed most during the difficult time of "technological stalemate (own translation)" and the dire times lead to a readiness to try the new and to neglect to some extent possible dangers as the first priority during the economically difficult time becomes to overcome it (pp. 144, 211). The meaning of Mensch's contribution to the research question is quite meaningful as one could argue that during the height of the utilization of a certain weapons technology and a war that is dominated by it, new ways to break through the "technological stalemate" and to gain an advantage over the status quo of armament technology are looked for and tested.

#### 2.3.2.4. Carlota Perez

Perez (2005) suggests a model that rests upon the emergence of innovations in clusters, "the functional separation between financial and production capital" and a certain slowness of the "socio-institutional framework" to adapt to the changing reality regarding technology and the economy. Her cycle with a duration of about 50 years includes the following elements: "*... technological revolution–financial bubble–collapse–golden age–political unrest"* (pp. 5–6). Perez' (2005) definition of "technological revolution" and the choice of the related innovations is relatively similar to the ones of other authors in the field. However, she adds the "big-bang", an incident that started the different revolutions. An example is "Stephenson's 'rocket'", which emerged in 1829 (pp. 8–11). Perez (2005) explains that it is not necessarily a new technology that leads to the revolution but that also a new combination of already existing ones can make the difference. Furthermore, usually new processes and ways of organizing production come along a revolution and change the reality meaningfully (pp. 13, 15). Approximatively the first half of the 50 years of each revolution comes along with problems in the field of "the social and regulatory systems", as an adjustment to the new reality takes time (Perez, 2005, p. 26). The above-mentioned inclusion of the two kinds of capital into her model works as follows: Perez (2005) explains that "financial capital" and "productive capital" are aligned at the start of each revolution and the former helps to fuel the revolution. However, as time passes, "financial capital" becomes more and more involved in excesses, which usually ends in a bust. The consequence is usually the re-establishment of order that aligns it again with "productive capital". Usually, economically prosperous times follow. During the last stages of the 50-year period, problems arise again (pp. 73–77).

## 2.4. Literature related to peace research

Also in the area of peace research, some meaningful studies related to the topic of this dissertation exist. Väyrynen and Kaldor contributed meaningful insights. They are especially interesting as both authors build upon the Kondratieff cycle to some extent.

### 2.4.1. Raimo Väyrynen

Väyrynen combines the Kondratieff cycle and armament technology. The insights he provides are highly relevant regarding the research questions:

> There seems to be an observable relationship between the long waves of economic development, technological innovation, leading industries complex and the nature of the arms race. Technological innovation and production capacity tend to define the succession of major weapons systems and in that way the image and reality of warfare should it break out. (Väyrynen, 1983a, p. 152)

Väyrynen (1983a) explains that economically difficult times are related to "military spending" for three reasons: investment by the state into the sector to face the economic crisis, worsening international relations as well as efforts for reaching "autarchy and protection". The end of the economically difficult times and the following upswing enable further investments into the area of the military and finally, large wars occur late in the rising part of the Kondratieff cycle and are further inflationary (p. 152).

Moreover, he provides examples concerning the relationship between military innovations and innovations related to the general technological development of the Kondratieff cycle: the general technological development in the field of "steel" enabled the building of naval vessels, which also found application in the military (Väyrynen, 1983a, p. 147). According to Väyrynen (1978), a further example for civilian R&D leading to new military weapons are "poisonous gases". Moreover, he explains that also the grade of organization of "military R&D" has increased, a state that was tied to times of military struggle before (pp. 177–178).

The cycles and leading industries Väyrynen (1990) works with are as follows: first cycle 1815 to 1872, driven by "iron industry and steam engines", second one 1873 to 1914, driven by "steel, electrical, and chemical industries", third one 1920 to 1967, driven by “cars and aircraft”, as well as the fourth one ever since 1968, driven by “telecommunications, computers, electronics, biotechnology” (p. 320). Apparently, he dates the Kondratieff cycles from top to top. Väyrynen (1983b) argues that ever since the Second World War, the meaning of the “contribution of technology to military policy” has changed meaningfully as many unprecedented implementations of technology are available now (pp. 61–62).

### 2.4.2. Mary Kaldor

Kaldor (1987) describes what she calls ”Atlantic Technology Culture”: “Atlanticism” as an ideology merged with societal organizations and political realities. At the same time, “Atlanticism” rests upon the assumption of “a bipolar model of the world”, where the power of the Western world is closely connected to “technological dynamism” (p. 143). In this context, she discusses the relationship between the general technological development and the one in the area of the military. As already stated above, Kaldor (1987) introduces the concepts of “‘spin-in’” and “‘spin-off’” to explain the reciprocity between general innovations and innovations in the area of the military (pp. 149–152).

## 2.5. Literature related to the military

The second strand of literature closely related to the topic of this dissertation is military literature. Relevant fields include the military classics focusing on warfare in general but especially on strategy and tactics. Furthermore, military literature related to the area of technology provides interesting insights.

### 2.5.1. Classics of military literature

Most of the military classics were children of their time and deeply rooted in the state of the art of military affairs at the time of writing. Van Creveld (1991) discusses the military classics with regard to their findings concerning technology related to war. The overview of older authors provided by him includes Sun Tzu, Thucydides, Caesar, Machiavelli, De Saxe, Jomini, as well as von Clausewitz and he concludes that they do not work extensively on the topic (p. 321). Exemplarily, von Clausewitz is discussed here for his prominent role. Indeed, technology and weapons do not play a major role in his work. However, Clausewitz (1980) argues that new ones were invented to gain superiority on the battlefield. This had an impact on “combat (own translation)” apparently but also did the “concept (own translation)” of it stay the same (p. 269). The impression arises that von Clausewitz accepted the changing of weapons over as he compared the different manifestations of war to a “chameleon (own translation)” (von Clausewitz, 1980, p. 212). Overall, it can be argued that von Clausewitz’ point of view stays above details in armament technology rather than that it is a missing point. Van Creveld (1991) concludes, “… a systematic, comprehensive theory of the relationship between technology and war is still not available. It would be highly desirable, and writing it would present an appropriate challenge for a new Clausewitz” (p. 323).

### 2.5.2. Military authors focusing on technology

Van Creveld (1991) provides an overview regarding the existing literature in the field of weapons technology (pp. 321–335). Many authors offer general insights but they provide little to the research questions per se. However, it is noteworthy that several authors writing on the topic use a scheme to categorize the various epochs covering different times of military technology. Fuller (1998) uses among others “the age of steam” as well as the “age of oil I” (p. VII). A more recent contribution is Boot (2007) who operates with characterizations like “the first industrial revolution” and “the information revolution” (pp. 107, 305). Clearly, the categorizations reflect economic and technological realities closely related to the concept of the Kondratieff cycle.

## 2.6. Conclusion from the general theoretical part: a theory of the emergence of groundbreaking innovations in weapons technology

It can be concluded that the research questions have not been satisfactorily addressed earlier. Nevertheless, the review of the existing literature shows that relevant ideas have been mentioned. Below follows the attempt to merge the necessary elements to a theory explaining the emergence of groundbreaking innovations in weapons technology during the last two centuries. The theory is split in two parts to deal with the changes that occurred during the time frame of this dissertation.

The **first part** deals with the $19^{th}$ century: it is assumed that by and large, groundbreaking innovations in weapons technology have arisen with a certain lag to the clusters of general innovations. From the background of general history, it seems fair to assume that the general technological development was more important and influenced the development of weapons meaningfully. Therefore, innovations in weapons technology are rather dependent on general innovations and follow temporally after the clusters of general innovations. This general expectation is in line with the observations by Schumpeter (2008) and Nefiodow and Nefiodow (2014) regarding general advances in the area of steel and weapons made of steel. Moreover, this expectation is in line with the above-mentioned relationship between general innovations and innovations in weapons technology. Furthermore, Dupuy's (1990) argument that changes in general technology made solving an existing problem in the field of weapons technology possible, which someone eventually did (p. 300) is included by accepting a certain lag between the clusters of general innovations and groundbreaking innovations in weapons technology. Defining a certain period for the lag is difficult, however. Rather, a somewhat random lag is accepted to deal with the loose connection.

The effect of war during the 19th century remains to some extent unclear. In general, it should have had a certain influence on the emergence of groundbreaking innovations in weapons technology. An example is the mentioned case of the construction of the modern cartridge, which Shields (1954) sees closely related to the American Civil War (p. 97). However, a strong link like in the 20th century seems not to exist.

The **second part** deals with the 20th century: a clustering around the two World Wars is assumed, which would be in line with the rise of the R&D sector, the totalization of war, as well as the increasing power of the state. State-induced research used the innovations from the field of general innovations and also developments from the area of weapons technology and finished them to gain an advantage during the war going on. Obviously, war had a strong impact on the development of groundbreaking innovations in weapons technology during the first half of the 20th century.

A further pillar of support in this regard is the finding by Mensch (1975) as discussed above: innovations arise when direly needed and help to overcome economically difficult times (pp. 144, 211). Transferring his statement to the field of military innovations means arguing for the emergence of groundbreaking innovations in weapons technology temporally closely connected to belligerent times, as they are developed to get an advantage in the recent war. The absence of a direct major war between powerful countries makes judging the second half of the 20th century difficult, however.

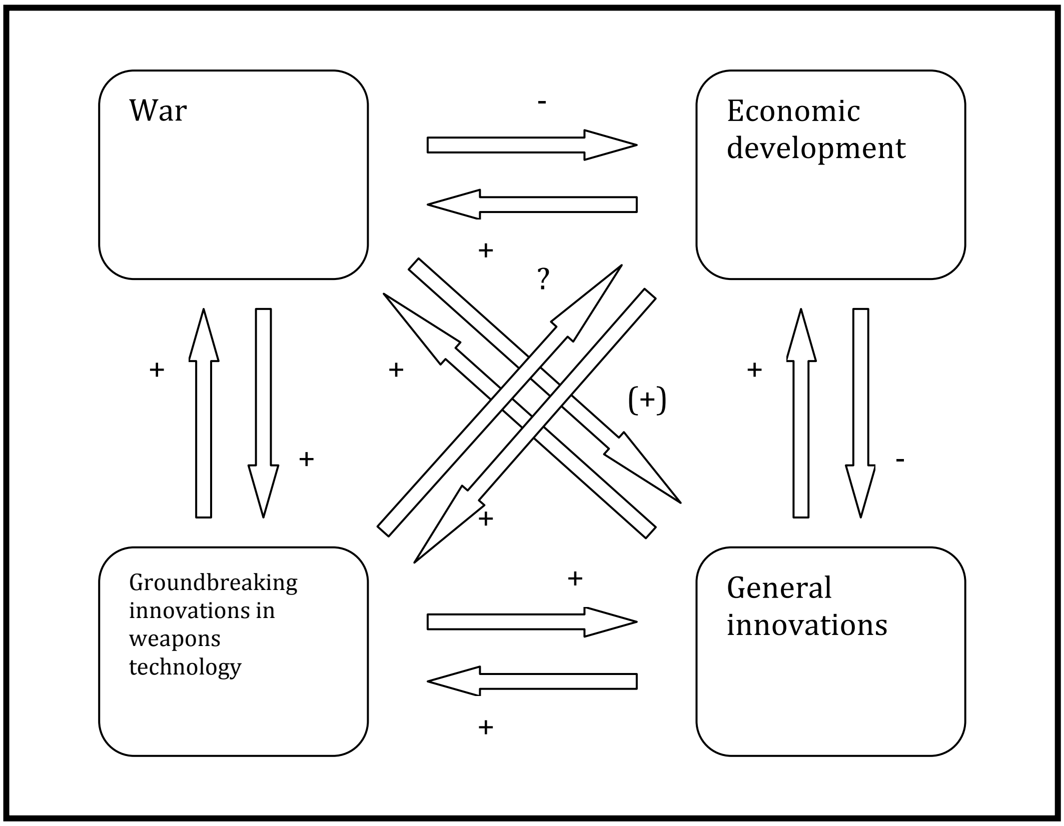


**Figure 6:** Relationship between war, economic development, military innovations, as well as general innovations.

The figure above illustrates the constructed theory and clarifies the relationship between the elements. It is inspired by Goldstein's (1988) model of the Kondratieff cycle (p. 275). The relationship between general innovations and economic development is assumed to be as Mensch (1975) suggested: good economic times do not come along with the necessity to innovate and try new things. Therefore, a positive economic development should come along with a dampening effect on general innovations. The emergence of a cluster of general innovations boosts economic development, however.

War should have a negative longer-term impact on economic development, which is in line with the literature discussed above, like for example Ayres (1935) or Tinbergen and Polak (1950). Economic development in turn should enable war to get more destructive. Groundbreaking innovations in weapons technology have the same effect on war. Nuclear weapons enable mankind to fight a war that would come along with unprecedented casualties. The occurrence of war should spur the development of groundbreaking innovations in weapons technology to some extent, as discussed above. General innovations foster the development of groundbreaking innovations in weapons technology. To some extent, this is also the case the other way round.

Economic development should have a positive effect on the development of groundbreaking innovations in weapons technology, as resources are created that can be used for R&D in the field of military technology. The net effect of groundbreaking innovations in weapons technology on economic development is somewhat unclear. The same applies to the net effect of war on general innovations. As mentioned above, it should have a certain positive effect. The strength of it is unclear, however. General innovations in turn should make more destructive wars possible.

# 3. Specific empirical part

This chapter explains the research questions as well as research methods and presents the results. Furthermore, it explains the research target group and the various limitations, which apply to this dissertation. An especially interesting feature is the set by Dupuy (1990), which can be seen as an attempt to falsify the results. The procedure is in the tradition of the discussion regarding the work of Mensch (1975): his procedure and results were heavily criticized and other authors checked his results with different sets and could by and large not falsify his work.

## 3.1. Empirical research questions and empirical research method

This dissertation deals with two research questions. The first one is: "How is the temporal connection between the long wave, major wars, as well as the general technological reality, to groundbreaking innovations in weapons technology?" The second one is: "Have groundbreaking innovations in the area of weapons technology emerged in a similar pattern as general innovations during the time frame of the last two centuries according to Mensch (1975)?" Presumably, groundbreaking innovations in weapons technology cluster as well. The expected pattern is explained in the general theoretical part above.
The research method applied is adopted from earlier research in the field and specified to the research questions of this dissertation. For each research question, an established approach is chosen.

### 3.1.1. Research method of research question 1

Devezas and Santos (2006) analyze the rise of "modern terrorism" since the second half of the 20$^{th}$ century by showing a sketchy Kondratieff cycle and marking important terroristic events on it. In a second step, they show the number of terroristic events from 1961 to 2004. They conclude that "modern terrorism" arose in the same pattern as technological innovations during the falling part of the Kondratieff cycle and gained full application in the decades thereafter only (pp. 245–248). Moreover, for example Nefiodow and Nefiodow (2014) use a similar procedure, as explained above. For this dissertation, some meaningful changes are performed to provide a better fit to the research question and to take into consideration the mentioned critique regarding the Kondratieff cycle. The sketchy Kondratieff cycle used by Devezas and Santos (2006) with "economic growth" on the y-axis is not used.
Instead, the rise of every innovation of the set presented in part 2.1.5.3. above is analyzed and important dates are determined as exactly as possible. Finally, a date is chosen, which marks the emergence of the innovation in the sense that it was available

on a level that made it ready for use ever since. Later, the dates of emergence are compared to the dates of the major wars determined by Levy (1983) to check how many innovations arose during years of war. Furthermore, the dates of emergence are compared to the technological reality defined by Nefiodow (1990) and Nefiodow and Nefiodow (2014). Doing so provides a better understanding of how the groundbreaking innovations in weapons technology are related to the advances in general technology.

Regarding the rise to full-scale application, the procedure by Devezas and Santos (2006) respectively Nefiodow and Nefiodow (2014) as explained above is used in case it is possible. For example, production numbers concerning nuclear weapons of the USA can be shown in the explained way. However, some innovations were paradigm changes. Therefore, all innovations are classified as follows: if the rise to full-scale application takes many years, for example if major powers accept a groundbreaking innovation 20 years after it has emerged only or if like in the case of the automobile, the number in use increases for many decades, it is categorized as a slow rise to full-scale application. If it is adopted almost instantly and in fact changes the military reality meaningfully, it is considered a paradigm change. An example is the ironclad, screw-driven steamer, which ended the time of wooden vessels used for warfare instantaneously.

### 3.1.2. Research method of research question 2

With regard to the second research question, the procedure used by Mensch (1975) is chosen. Building upon the results of the first research question regarding the years the groundbreaking innovations in weapons technology have emerged; their number per decade for the time frame of this dissertation is shown in a figure. The visualization enables a direct comparison to Mensch's (1975) results. A qualitative discussion of the innovations and their nature provides a better understanding of the pattern of emergence.

## 3.2. Target group of this dissertation

This dissertation contributes first and foremost to the literature related to the Kondratieff cycle. To some extent it contributes to military literature and peace research as well.

It builds upon the work of Mensch and others but focuses on weapons technology. Therefore, it augments the findings of the literature related to the Kondratieff cycle with a focus on technology. Furthermore, it contributes to peace research like the work of Väyrynen (1983a) and Kaldor (1982, 1987), as it augments their findings. Regarding military literature, it provides a macro perspective regarding the development in the area of weapons technology from the background of the literature tied to the Kondratieff cycle and innovations. Moreover, it puts the development of innovations in this special field into perspective concerning the findings and theories regarding the emergence of general innovations. The insights might help to some extent to develop van Creveld's (1991) suggestion of a "… systematic, comprehensive theory of the relationship between technology and war …" (p. 323).

## 3.3. Limitations

A certain amount of limitations applies to this dissertation. Three major points can be identified: changes in the system, the change of the lethality of weapons over time, as well as the meaning of tactics and strategy.

### 3.3.1. Changes in the system

Van Creveld (1991) sees a major change around the year 1830, as it is the beginning of steady development in weapons technology, which was not the case before (pp. 217–218). Related is the "qualitative arms race", which he sees incorporated since 1860 and which pressed states not to lose contact with the most recent technological development of arms (van Creveld, 1991, pp. 223–224). Another, related change made war at least on a theoretical level more continuous: McNeill (1984) mentions that the German "Great General Staff" was founded in the first decade of the 19th century and its purpose was preparing for future wars (p. 217). This fact can also be seen as a further change in the system, as also other countries adopted similar institutions later on. Additionally, the Second World War came along with the creation of structures, organizations etc. that remained afterwards, like in the area of "R&D" (Brauch, 1990, p. 175). The mentioned process has changed the field of military technology and innovations and makes comparability difficult. This point is close to the general critique by Solomou (1986) concerning the comparability of innovations over time, as during the last two hundred years, the "factors determining the propensity to innovate" have changed (p. 103).

### 3.3.2. Change in the lethality and complexity of weapons

Regarding weapons, their lethality has risen meaningfully over time. Even though the computation and comparison of lethality might be difficult, it nevertheless tackles an important phenomenon. Dupuy (1990) provides data on the lethality of arms over time with his "theoretical lethality index". His results suggest that the lethality has risen meaningfully during the time frame covered by this dissertation (p. 92). The fact of a changing lethality might not mean that comparison of different weapons is impossible; it should be kept in mind when doing so however. Nevertheless, not only improvements in technology, but also improvements in the fields of manufacture and logistics enabled the escalation of armed conflicts in general (Levy, 1983, p. 146).

A related phenomenon is the one of the rising intricacy of weapons: Kaldor (1982) argues for a meaningful increase in the intricacy of weapons ever since the Second World War, which is also displayed by the exploding costs. She mentions price increases by the factor of 200 for "bombers" and 15 for "battle tanks" for the period from the Second World War until her publication (p. 25).

#### 3.3.3. Meaning of strategy and tactics

Another important point is that looking at military innovations or weapons only means not looking at how they are used, namely tactics. However, innovative arms gain their full meaning in combination with appropriate tactics only (Dupuy, 1990, pp. 287, 290). Examples are the use of the mitrailleuse, an early machine gun, which was initially used like artillery (Brodie & Brodie, 1973, p. 145) or the tank, whose appropriate tactic was misunderstood during the early years (Brodie & Brodie, 1973, p. 198). Van Creveld (1991) goes one step further and mentions that it is not sufficient to change tactics only, but that operational as well as strategic changes might be due. As an example he mentions the proper utilization of the Zündnadelgewehr (p. 227).

### 3.4. Empirical results

The following two parts show the empirical results regarding the two research questions. The results of research question 1 obtained below enable dealing with the second one afterwards.

#### 3.4.1. Research question 1

The 23 groundbreaking innovations are treated as explained above regarding the question how they have arisen and spread afterwards. A short introduction explains the historical background and provides a definition where needed. Then, the development is described as well as the rise to full-scale application. Finally, a conclusion summarizes the insights and gives the year the groundbreaking innovation in weapons technology emerged.

#### 3.4.1.1. Percussion cap

The percussion cap can be described as follows: according to Pauly (2004), it consists of a metal cap, which is usually made of copper. It is filled with a small amount of “mercury fulminate”, which makes it sensitive to shock. It can be fitted on a percussion lock. When firing, the cock hits upon it, triggers a small explosion, which in turn burns through a tiny hole into the barrel and ignites the gunpowder (pp. 81–82). Using the percussion cap made possible firing in a drenched environment as well and brought down the rate of malfunctioning by almost 90% (Fuller, 1998, p. 113). Furthermore, the percussion cap was suited for large-scale production and it reduced the amount of gases lost during firing (Pauly, 2004, p. 83).

##### 3.4.1.1.1. Development of the percussion cap

Overall, the development of the percussion cap was dependent on an explosive sensitive to shock (Fuller, 1998, p. 112). Therefore, the early phases of development are closely related to the discovery and production of fulminates, which are the salts of fulminic acid. The earliest known is “fulminating gold (own translation)”, which Crollius mentioned in 1608 already (Gartz, 2007, p. 104). To be precise, it is not a true fulminate, however. Van Drebbel might have been aware of “mercury fulminate (own translation)” in 1621 and von Löwenstjern in 1690 already (Gartz, 2007, pp. 111–112). During the 1780s, Berthollet worked with fulminates (Pauly, 2004, p. 80). Forsyth started working in the field of percussion in 1793 already (Brodie & Brodie, 1973, p. 131). The next important step occurred in 1798, when Brugnatelli created “‘fulminating silver’” (Fuller, 1998, p. 112). A year later Howard produced “mercury fulminate (own translation)” (Gartz, 2007, p. 110), the advantage of the mercury compound is the lower price (Brodie & Brodie, 1973, p. 131), as well as the easier manageability compared to other fulminates (Gartz, 2007, p. 110). In 1807, Forsyth got a patent for his “percussion lock” (Pauly, 2004, p. XVII). According to Pauly (2004), his system worked with a small box of mercury fulminate, which could extract a small amount sufficient for igniting one shot. When shooting, the mercury fulminate was ignited by concussion, which ignited the gunpowder (p. 81). Held (1970) adds that the mentioned container held enough primer for igniting 25 shots and that the probability of misfire was extremely low, even in bad weather (p. 171). According to Held (1970), another streak of development occurred approximatively around 1814, namely the use of “small rolled pills or pellets” containing the explosive, which were positioned in a mount above the hole leading into the chamber. A hammer beating upon it ignited the explosive and that in turn the main charge. The design was susceptible for wetness, however. Manton improved it and got two related patents, one dating from 1816 and one from 1818. The first one relates to a “pill system”, the second, better one, to the “*percussion-tube* lock”. It worked with a small pipe filled with shock-sensitive explosive and was inserted into a small hole of the barrel. A hammer beating upon it sealed the upper opening to a large extent and ignited the shot (p. 174). However, the final design becoming widely used looked somewhat different, namely as described above in the introduction concerning the percussion cap. Shaw developed a percussion cap made of steel in 1814 and one made of copper in 1816, even though there were others arguing it was their invention (Fuller, 1998, pp. 112, 128). The production of percussion caps was easy and inexpensive, while they were reliable (Pauly, 2004, pp. 81–83). For the sake of wholeness, the system working with a tape of paper has to be mentioned as well. According to Pauly (2004), it was developed by Maynard in 1845 and consisted of two tapes of paper with small heaps of explosive sensitive to shock in between. The tape was rolled up and cocking transported a new part with a heap of explosive towards the touchhole. Overall, it was not as reliable as the metallic percussion cap and was briefly used in the army of the USA only and rejected soon (pp. 84–85).

**Meaningful events related to the development of the percussion cap**

1. 1780s: Berthollet works with “fulminates” (Pauly, 2004, p. 80).
2. 1793: Forsyth starts working in the field of percussion with regard to firearms (Brodie & Brodie, 1973, p. 131).
3. 1798: Brugnatelli creates “‘fulminating silver’” (Fuller, 1998, p. 112).
4. 1799: Howard is able to produce “fulminate from mercury” (Pauly, 2004, p. 80).
5. 1805: Forsyth develops some kind of percussion lock working with “mercury fulminate” as a primer (Carman, 1955, p. 177).
6. 1807: Forsyth gets a patent for his “percussion lock” (Pauly, 2004, p. XVII).
7. 1814: Shaw develops the percussion cap made of steel (Fuller, 1998, p. 112).
8. 1816: Shaw develops the percussion cap made of copper (Fuller, 1998, p. 112).
   1816: Manton gets a patent for his “pill system” (Held, 1970, p. 174).

**3.4.1.1.2. Full-scale application of the percussion cap**

The standard weapon dominating the scene of warfare before the innovations dealt with in this dissertation appeared was the so-called Brown Bess, which had a flintlock and was a muzzle-loader. Great Britain started to equip her army in 1703 with this

smooth-bore arm (O'Connell, 1989, p. 158). The output figures are approximatively 7,800,000 units and it was used for almost one and a half century (Held, 1970, p. 113). The muskets used by other countries at that time were not very different (Pauly, 2004, p. 56). Since 1820 did the percussion cap become established, a fact fueled by the easiness of changing a flintlock to a percussion lock (Brodie & Brodie, 1973, p. 132). In fact, hundreds of thousands guns were changed to the new system (Held, 1970, p. 174). Starting with tests in 1834, Great Britain opted for "… the conversion of flint-lock muskets to the percussion principle" in 1839 (Fuller, 1998, p. 112). The decision to equip new weapons with the percussion system was reached in Great Britain a year earlier already (Pauly, 2004, p. 84). France came to the same conclusion in 1840, the USA in 1842 (North & Hogg, 1977, p. 83; as cited in Pauly, 2004, p. 84). Held (1970) summarizes that "… the last afterglow of the 325-year history of firelocks was totally extinguished by 1840" (p. 175). In 1836, the quantity of produced "percussion caps (own translation)" reached 800,000,000 in France alone (Gartz, 2007, p. 115).
Great Britain adopted the Brunswick rifle in 1838 (Pauly, 2004, p. XVIII), which was the first model using the percussion lock introduced by Great Britain (Carman, 1955, p. 110). Great Britain adopted the Minié rifle and produced 28,000 units in 1853 (Rüstow, 1971, p. 34), which also used the percussion lock. Pauly (2004) explains that in 1853 the "'Enfield Rifled-Musket'" was developed and subsequently become service rifle of the army of Great Britain. The caliber of the bore was .577 and the related ammunition a Minié ball caliber .575 (p. 75). The mentioned model used a percussion lock as well, stayed in service for quite a while and was later converted to the use of cartridges.
The army of the USA started to use the "percussion cap" in 1842 (Shields, 1954, p. 61). The USA opted for the "Springfield Model 1855" in 1855 (Pauly, 2004, p. XVIII). The ignition system developed by Maynard was unsatisfactory, as described above, and therefore the "Springfield Model 1855" was replaced by the "Springfield Model 1861" (Pauly, 2004, pp. 84–85). Pauly (2004) mentions further that the latter was the standard weapon of the American Civil War. It used percussion caps and had a meaningful similarity to the British Enfield (p. 77). Davis (1998) writes that particularly the armed forces of the North relied upon the different models of the „U.S. Springfield rifle" during the American Civil War. They bought 1,472,614 of them and additionally 428,292 Enfield rifles, which taken together amounts to 75% of all long guns bought by the armed forces of the North (p. 54).

#### 3.4.1.1.3. Conclusion regarding the percussion cap

The year of the groundbreaking innovation percussion cap is 1816. Even earlier systems might have worked like Forsyth's lock or the locks using pills but the design utilizing copper manifests the completion of the percussion cap. The design was widely used afterwards and a very similar design is available until today. Also is a small percussion cap integral part of modern center fire cartridges.
Regarding military utilization, Great Britain adopted the percussion cap in 1838, 22 years after Shaw's design emerged. In the USA, it took 26 years. The percussion cap is therefore categorized as a groundbreaking innovation with a slow rise to full-scale application.

#### 3.4.1.2. Railway

Geistbeck (1986) writes that around the year 1500 rails made of wood appeared in Germany to facilitate transportation inside mines. Later on, they were improved by partially reinforcing them with iron. This system was soon used in Great Britain, where the rail made of iron emerged in 1767 (p. 209).

#### 3.4.1.2.1. Development of the railway

The problem of quick and efficient propulsion was still unsolved, however. A notable early device, even though unrelated to rails, was the steam-powered one by Cugnot, dating from 1769 (Grant, 2005, pp. 10–11). Watt patented a crude steam-driven locomotive in 1784 without meaningful application, however (Geistbeck, 1986, pp. 210–211). The first locomotive propelled by steam to be taken seriously and able to pull a small train on rails was the one by Trevithick that appeared in 1804 and was "… presumably the world's first steam locomotive" (Grant, 2005, p. 11). Geistbeck (1986) mentions that Stephenson started working in the field of locomotives in 1813. In the following year, his first design was ready. A patent regarding an improved design dates from 1815 (p. 214). Stephenson's "*Locomotion No.1*" dates from 1825, which he constructed for Stockton and Darlington, "… the world's first modern railroad" (Grant, 2005, p. 11). Four years later, he built the "*Rocket*", an especially efficient locomotive (Grant, 2005, p. 11).

**Meaningful events related to the development of the railroad**

1. 1804: Trevithick completes his device, which is "… presumably the world's first steam locomotive" and travels on rails (Grant, 2005, p. 11).
2. 1814: Stephenson completes his first and still flawed model (Geistbeck, 1986, p. 214).
3. 1815: Patent by Stephenson regarding his improved design (Geistbeck, 1986, p. 214).
4. 1825: Stephenson's "*Locomotion No. 1*" constructed for Stockton and Darlington, "… the world's first modern railroad" (Grant, 2005, p. 11).

### 3.4.1.2.2. Full-scale application of the railway

With regard to early applications of the railway during wars, the following applies: Ellis (1986) writes that during the American Civil War, it was employed to a meaningful extent for logistic tasks (p. 48). This was also the case during the Austro-Prussian War as well as the Franco-Prussian War (van Creveld, 1991, p. 159). With regard to the latter, O'Connell (1989) remarks, "… within eighteen days, the railway system delivered an army of almost five hundred thousand to the French border" (p. 207). They were employed very efficiently for mobilization but their role during the wars themselves was nevertheless limited (van Creveld, 1977, pp. 84, 96). The German General Staff used the combination of railway and telegraph heavily, enabling rapid movement of forces as well as the possibility to communicate with troops in the field (O'Connell, 1989, p. 203). Railway lines in Prussia were built also taking into consideration the interests of the military planners in the General Staff (O'Connell, 1989, p. 204). The importance of the railway remained high during later wars, like the First World War.

Apart from the early qualitative meaning for warfare stressed above, figures 7 and 8 display the general meaning of the railway in the USA and Great Britain. Both figures show strong growth during the early decades and some kind of saturation around the end of the $19^{th}$ century. It is interesting to see the decline of railway lines as well, which nevertheless does not necessarily mean that the meaning of the railway declined also.

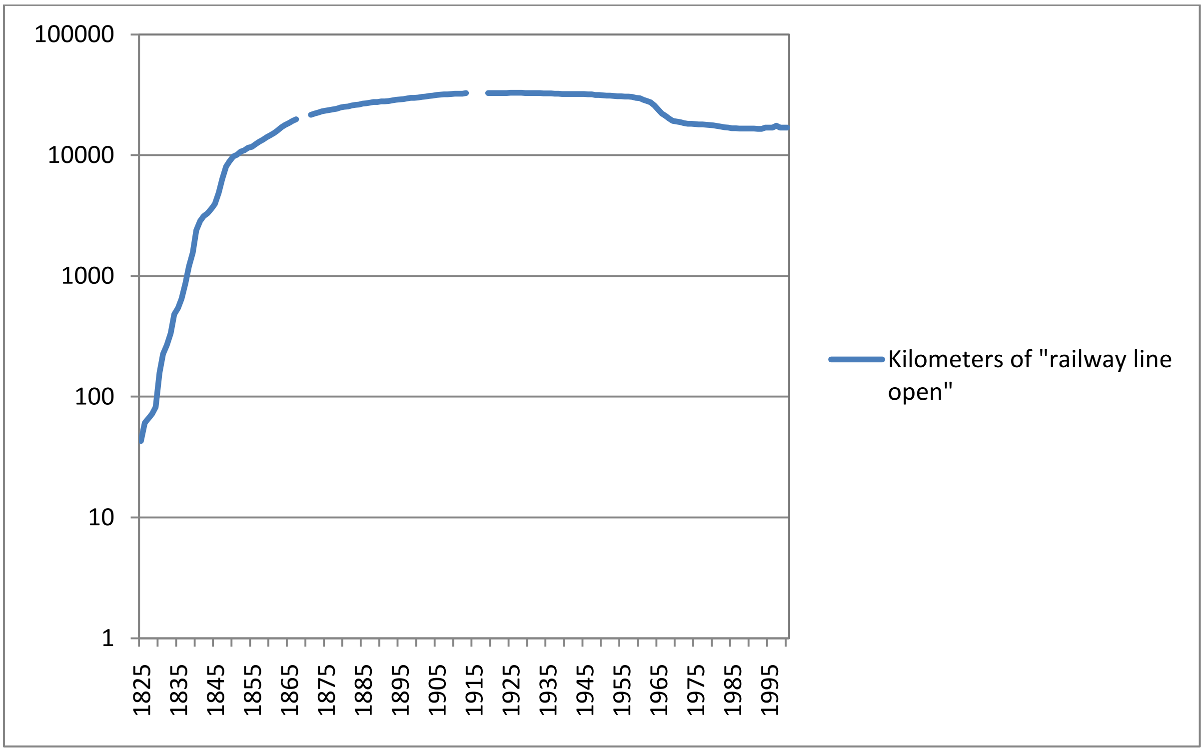


**Figure 7:** "Length of railway line open" in Great Britain, 1825–2000.
(Own depiction, based upon Mitchell, 2003a, pp. 674–682)

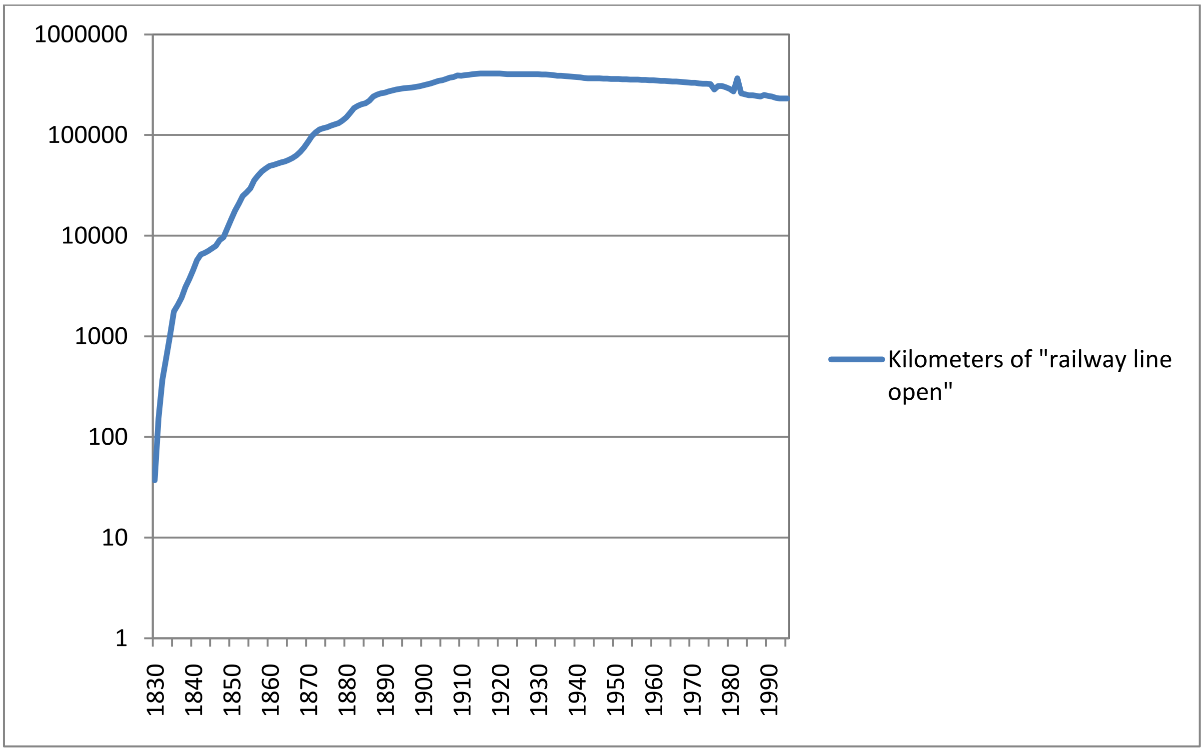


**Figure 8:** "Length of railway line open" in the USA, 1830–1995.
(Own depiction, based upon Mitchell, 2003b, pp. 539–544)

### 3.4.1.2.3. Conclusion regarding the railway

The year 1825 is chosen as the year the innovation railway appeared. It was the year of the construction of Stephenson's locomotive for Stockton and Darlington. The rise to full-scale application is categorized as a slow one. The railway is a groundbreaking innovation in weapons technology that is at the same time the basis innovation of the second Kondratieff cycle in Nefiodow and Nefiodow's (2014) scheme.

### 3.4.1.3. Breech-loading rifle

As already mentioned above, the standard weapon dominating the scene of warfare before the innovations dealt with in this dissertation appeared was the so-called Brown Bess, which had a flintlock and was a muzzle-loader. The groundbreaking innovation breech-loading rifle consists of two major innovations: using a rifled barrel as well as breech-loading the weapon. The mentioned two elements appeared to some extent separately. Therefore, they are analyzed separately as well. Hogg (1970) explains the advantage of rifling:

> The object of rifling is to impart a twist to the projectile on leaving the bore, thereby giving it a rotational velocity which, increasing its steadiness in flight, extends its range and gives more accuracy. (p. 80)

The advantages of breech-loading include an increase of the rate of fire as well as the possibility to reload without the need for the shooter to stand upright (Fuller, 1998, p. 118), which means among others that the person loading is less exposed to enemy fire.

### 3.4.1.3.1. Development of the rifle

Pauly (2004) writes that the first known rifle is one that belonged to Maximilian I. and dates from the period 1493–1508 (p. 61). The first adoption of rifles by military units might have taken place as early as 1631 by units of the "Landgrave of Hesse" (Fuller, 1998, p. 128). However, a noteworthy if also limited impact on warfare concerning rifles took place during the Seven Years' War and War of American Independence only (Pauly, 2004, pp. 64–65). According to Pauly (2004), units equipped with rifles were used by Great Britain during the American War of Independence as well as during the Napoleonic Wars. Also Russia used rifles against the Napoleonic troops (pp. 65–68). During the War of American Independence, Great Britain used the breech-loading Ferguson rifle and during the Napoleonic wars the muzzle-loading Baker rifle (Pauly, 2004, pp. 65–68). In 1800, the first unit of Great Britain was formed that was armed with the "Baker rifle"; however, a large-scale use did not occur perhaps for the high cost (Carman, 1955, pp. 109–110). Great Britain adopted the

Brunswick rifle in 1838 (Pauly, 2004, p. XVIII), which was another important early model. In 1855, Rüstow (1971) concluded from the happenings of the Crimean War, that the rifle rendered the smooth-bore musket obsolete (p. 1).

### 3.4.1.3.2. Full-scale application of the rifle

The army of Russia used about 20,000 "Tula rifled muskets" for fighting the Napoleonic troops, the model was "… the only rifled musket to be issued to any infantry in moderately large quantities before the 1840's …" (Held, 1970, pp. 114, 152).

Great Britain adopted the Minié rifle and produced 28,000 units in 1853 (Rüstow, 1971, p. 34). Pauly (2004) explains that in 1853 the "'Enfield Rifled-Musket'" was developed and subsequently become service rifle of the army of Great Britain. The caliber of the bore was .577 and the related ammunition a Minié ball caliber .575 (p. 75). After the Crimean War, also in Great Britain modern production processes based upon the use of machines as developed in the USA set in (O'Connell, 1989, p. 192). Subsequently, Great Britain produced 250,000 Minié balls as well as 200,000 "finished cartridges" daily (Hogg, 1963, pp. 792–793; as cited in O'Connell, 1989, p. 192). Smooth-bore muskets were sorted out by the military of Great Britain by 1859 (Carman, 1955, p. 104). All meaningful service rifles of Great Britain ever since have been rifled.

The USA opted for the "Springfield Model 1855" rifle in 1855 (Pauly, 2004, p. XVIII). The ignition system developed by Maynard was unsatisfactory and therefore the "Springfield Model 1855" was replaced by the "Springfield Model 1861" (Pauly, 2004, pp. 84–85). Davis (1998) writes that particularly the „Union Army" relied upon the different models of the „U.S. Springfield rifle" during the American Civil War. They bought 1,472,614 of them and additionally 428,292 Enfield rifles, which taken together amounts to 75% of all long guns bought by the „Union Army" (p. 54). All meaningful service rifles of the USA ever since have been rifled.

### 3.4.1.3.3. Development of the breech-loading rifle

Henry VIII acquired a considerable amount of breech-loaders already (Held, 1970, p. 61), which means that they date roughly from the first half of the $16^{th}$ century. According to Pauly (2004), the related technological difficulties however made reliable breech-loaders on a large scale impossible until the production methods linked to the Industrialization emerged (pp. 65–67). Pauly (2004) explains that the breech-loading rifle developed by Ferguson was based upon earlier designs and used a “breechblock”. Ferguson presented his design to the king in 1776 and a small unit of 100 men was created, armed with his rifle. The mentioned unit fought during the American War of Independence (pp. 65–67). In fact, it was “… the first British rifle unit” and first official unit in the world using rifles that were breech-loaders (Carman, 1955, pp. 107–108). A patent regarding Ferguson’s model dates from 1776 but only about 200 units were manufactured (Held, 1970, pp. 150–151). According to Pauly (2004), Hall got a patent for his breech-loading model in 1811, which he improved in 1833 by changing the ignition to the percussion system. Overall, his products were not satisfactory regarding the old problems of breech-loading arms like not being gastight but still represent the better models of the time after the Ferguson rifle. Hall’s rifle was used during the Mexican war (pp. 90–91). Held (1970) adds that it was the “… first official U.S. breechloader …”, entering service in about 1820 (p. 182). Another important design was the one developed in Norway in 1842 (Pauly, 2004, p. 91). The model was called Kammerlader and also used to equip the Norwegian army.

The Zündnadelgewehr or needle gun developed by Dreyse was the first truly workable design. Fuller (1998) explains that Dreyse developed the first reliable model during the period 1824 to 1836. The advantages included an increase of the rate of fire compared to the Minié rifle by a factor of more than three as well as the possibility to reload without the need for the shooter to stand upright. The Minié rifle’s range was larger, however (p. 118). According to Held (1970), the “*needle gun*” was the “… world’s first military cartridge breechloader” (p. 184). Dreyse improved his design in 1840 (R. Wirtgen, 1991, p. 71) and Friedrich Wilhelm IV. of Prussia ordered 60,000 of them in the same year (Kölling, 1991, p. 70). Pauly (2004) explains the mechanism of Dreyse’s device as follows: a “cartridge” with the priming charge located behind the projectile and followed by the gunpowder could be inserted after opening the gun by rotating the “sliding breech-block” counterclockwise and moving it back. Doing so also cocked the ignition mechanism. Closing it again by moving the “sliding breech-block” back in position made it ready to fire. The long needle from which the gun derived its name was necessary to reach the priming charge for ignition (pp. 95–96).

**Meaningful events related to the development of the breech-loading rifle**

1. 1800: First unit in Great Britain equipped with the Baker rifle (Carman, 1955, p. 109).
2. 1803–1812: 20,000 “Tula rifled muskets” used by Russia against Napoleonic forces (Held, 1970, p. 152).

3. 1811: “American John Hancock Hall patents a breech-loading rifle and later perfects the manufacture of standardized parts” (Pauly, 2004, p. XVII).
4. About 1820: Hall’s model becomes the “… first official U.S. breechloader …” (Held, 1970, p. 182).
5. 1824–1836: Dreyse develops the Zündnadelgewehr (Fuller, 1998, p. 118).
6. 1836: “*Needle gun*” patented by Dreyse (Held, 1970, p. 184).
7. 1840: Dreyse improves his design (R. Wirtgen, 1991, p. 71). Friedrich Wilhelm IV. of Prussia orders 60,000 of them (Kölling, 1991, p. 70).

**3.4.1.3.4. Full-scale application of the breech-loading rifle**

The Austro-Prussian War confirmed the predominance of Dreyse’s model relative to the rifle used by Austria that was not a breech-loader (Fuller, 1998, p. 119). Afterwards, all meaningful European armies adopted the breech-loading system, for instance chose France the Chassepot model (Pauly, 2004, p. 96). Regarding production numbers of the needle gun, Boot (2007) writes that in 1840, Prussia bought 60,000 pieces. During the early years however, the yearly production numbers were 10,000 only, later on 22,000. Only in 1866, all soldiers of Prussia were equipped with it (p. 129). In 1870, 448,510 units of the original version „M/41“ were available (Lehmann, 1905, Anl. 8, pp. 223–224 ; as cited in R. Wirtgen, 1991, p. 74). The number of all models and variants that were available in 1870 was 1,068,942 (Lehmann, 1905, p. 19, Anlage 8; as cited in A. Wirtgen, 1991, pp. 199–200).

Pauly (2004) describes that after 1864, Great Britain decided to modify the existing Enfield rifle to a breech-loader, which used a „brass center-firecartridge“ developed by Boxer. The modified Enfields were later replaced by the „Martini-Henry“ (pp. 106, 108–109). The year the conversion suggested by Snider for the Enfield was accepted is 1867 (Reynolds, 1960, p. 18).

The development regarding the USA can be described as follows: Keegan (2010) mentions that during the American Civil War, most guns used were not “breech-loaders (own translation)”, only some units of the North were equipped with them (p. 88). According to Davis (1998), the Union bought about 90,000 of Sharp’s breech-loaders during the American Civil War (p. 62). The USA reconfigured the Springfield rifles also to the breech-loading system and they stayed in service until the 1890s (Pauly, 2004, p. 108). The year of the conversion was 1866 (Shields, 1954, pp. 98–101).

### 3.4.1.3.5. Conclusion regarding the breech-loading rifle

As can be seen above, the appearance of rifles and breech-loading rifles was a protracted development. Many different designs were used, in most cases only on a limited scale. Staying in line with the definition for groundbreaking innovations in weapons technology of this dissertation, only the needle gun by Dreyse can be accepted. It was issued in large quantities and made a difference during the Austro-Prussian War. Afterwards, all major powers opted for breech-loading rifles. The year of Dreyse's improved version and large-scale order by Prussia, 1840, marks the appearance of this groundbreaking innovation. Also van Creveld (1991) sees it as „the first practical breech-loading rifle" (p. 220). Shields (1954) even sees it as the fundament for the development of most later rifled shoulder arms for the military until 1945 (p. 91). The rise to full-scale application was as protracted as the development. Whereas Prussia started to use this innovation since 1840, Great Britain only did so after 1867 and the USA after 1866, a lag of 27 and 26 years, respectively. It is therefore categorized as a slow rise to full-scale application.

### 3.4.1.4. Telegraph

Van Creveld (1991) explains that "optical telegraphs" were used on a large scale in Ancient Rome already. However, the fact that optical instruments to augment the power of human vision were not available yet limited the effectiveness of the early models (p. 154). According to Mercer (2006), the first usable modern models were optical devices like the ones of two brothers Chappé, working with optical instruments to enhance the distance covered. In 1791, they presented their system successfully. Subsequently, the system was improved and expanded; the military was a user of it. A similar system was installed in Great Britain beginning in 1795 (pp. 2–5). Van Creveld (1991) stresses the military meaning of the Chappé system in France and similar ones in other countries like Great Britain, Prussia, and Russia (pp. 155–156).

### 3.4.1.4.1. Development of the telegraph

Mercer (2006) writes that a large variety of designs using electricity appeared in the period 1753 to 1837. Henry provided theoretical contributions, for example how to deal with the problem of decreasing signal power related to the length of the cable. In the field of usable devices, Cooke and Wheatstone got a patent for their model in 1837. "Great Western Railway" sponsored the development of a "telegraph" of the type suggested by Cooke and Wheatstone and soon, more were constructed. In 1845, Cooke even did business with the "British Admiralty", his task was to connect

Portsmouth with London. Later on, the branch of telegraphy flourished (pp. 5–8). The system of Cooke and Wheatstone had shortcomings however (Regal, 2005, p. 9).
A similar development occurred in the USA. Mercer (2006) notes that already in 1832, Morse developed the idea of his design. Five years later, he worked again on his idea, asking specialists like Henry, Gale, and Vail for assistance. Vail for example helped to develop the relatively efficient Morse "code". Morse patented his design in the USA in 1840, while a patent was denied in Great Britain in 1838 because of the earlier one by Cooke and Wheatstone. In 1844, "the first official message" reached Washington from Baltimore using Morse's telegraph. By 1851, the design by Morse also started to dominate the telegraphy branch in Europe (pp. 8–14).

**Meaningful events related to the development of the telegraph**

1. 1820: "Hans Christian Oersted in Denmark notes that electricity passing through a wire has an effect on compass needles because it produces a magnetic field" (Mercer, 2006, p. XVI).
2. 1820s to 1830s: "Joseph Henry in the United States performs experiments with electromagnets and telegraph devices" (Mercer, 2006, p. XVI).
3. 1833: Telegraph by Gauß and Weber (Mensch, 1975, p. 152).
4. 1837: Patent by Cooke and Wheatstone in Great Britain regarding "a needle electric telegraph" (Mercer, 2006, p. XVI).
5. 1840: Morse patents his "electric telegraph" (Mercer, 2006, p. XVI).
6. 1844: "The first official Morse telegraph message is sent from Baltimore to Washington …" (Mercer, 2006, p. XVI).

### 3.4.1.4.2. Full-scale application of the telegraph

Mercer (2006) describes the quick proliferation in many countries and that especially in Great Britain, the development of railroads and the telegraph were closely connected. Particularly in the USA, the possibility to spread information rapidly made the telegraph interesting for different industries (pp. 14–15).
The German General Staff used the combination of railway and telegraph heavily, enabling rapid movement of forces as well as the possibility to communicate with troops in the field (O'Connell, 1989, p. 203). Already during the Crimean War, the telegraph was used on a relatively large scale and it became clear already that orders from the rear transmitted by telegraph and based upon little knowledge of what is going on at the front can be problematic (Raines, 2011, p. 4). Brodie and Brodie (1973) explain that the telegraph was mostly used strategically during the American

Civil War. On a tactical level, more traditional ways of communication were used like optical devices or messengers (p. 130). The situation during the First World War looked as follows regarding the army of the USA: as devices for wireless transmission were still heavy and not suited for use in the field, the main devices used by the army of the USA during the First World War were telephones and for longer distances telegraphs (Raines, 2011, pp. 185–186). Also messengers, on foot, or for example using a horse, were employed, as well as pigeons and optical devices (Raines, 2011, p. 188). Concerning the army of Great Britain, actual numbers regarding the same time frame are as follows: the communications traffic of "a single British field army" amounted to "… 10,000 telegrams, 20,000 telephone calls, and 5,000 messages forwarded by the Military Dispatch Service" per day (Evans, 1935, p. 29; as cited in van Creveld, 1985, p. 158).

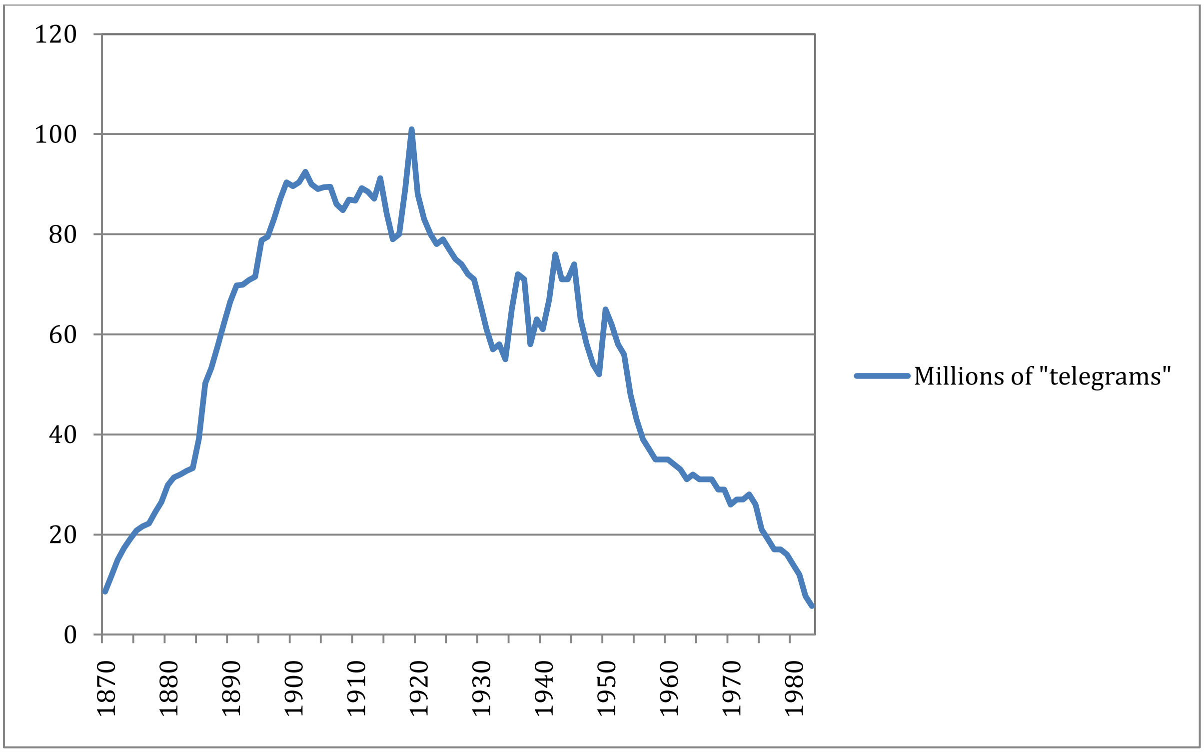


**Figure 9:** Millions of "telegrams" per year in Great Britain, 1870–1983.

(Own depiction, based upon Mitchell, 2003a, pp. 752–762)

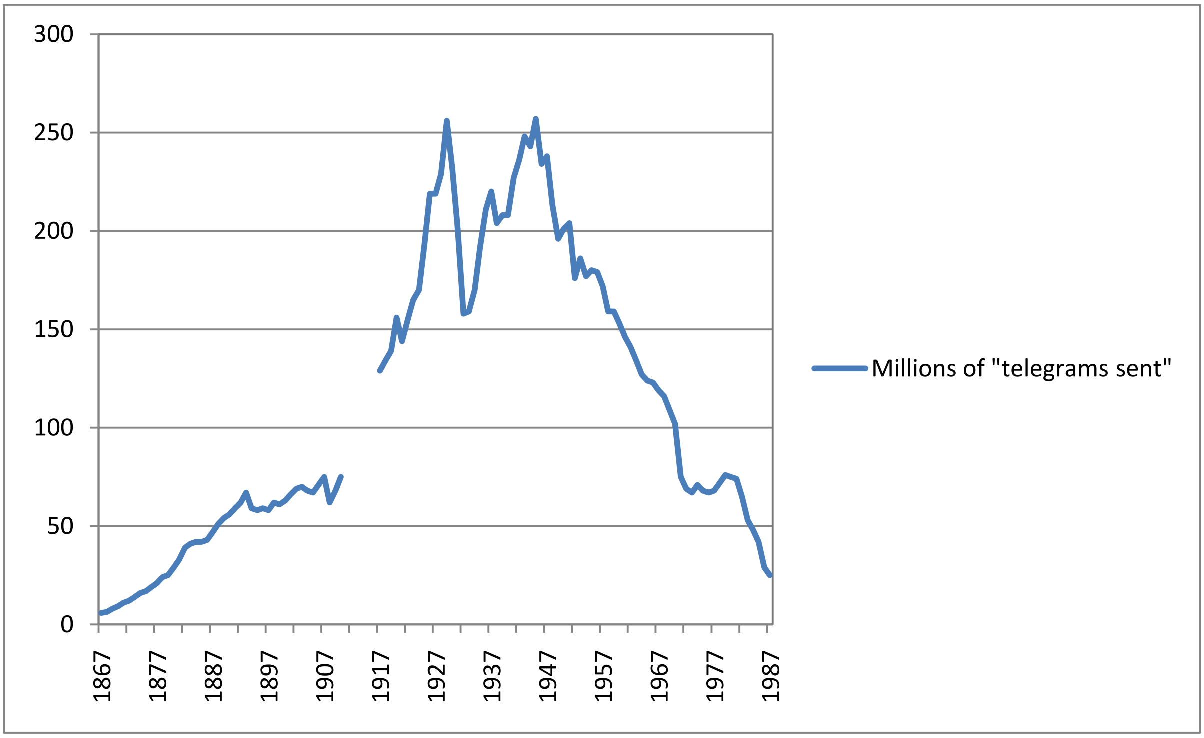


**Figure 10:** Millions of "telegrams sent" per year in the USA, 1867–1987. (Own depiction, based upon Mitchell, 2003b, pp. 610–612)

Figures 9 and 10 show the spread of the telegraph system in Great Britain and the USA. The number of telegrams can be seen as an adequate measure for showing the arising meaning of the telegraph in general over time, supporting the remarks regarding full application above with data.

#### 3.4.1.4.3. Conclusion regarding the telegraph

The year 1844 is chosen for the groundbreaking innovation telegraph. It is the year Morse sent his first message. Even though the earlier system of Cooke and Wheatstone worked as well, only Morse's system including his code soon dominated the telegraphy branch globally. The figures provided above suggest that it was rather a slow rise to full-scale application. They also display the ensuing decline of this innovation.

#### 3.4.1.5. Breech-loading, rifled artillery

According to Fuller (1998), the earliest cannons utilizing black powder date from the first half of the 14th century, while the earliest cannon that was a breech-loader might have appeared around the year 1400. Rifling appeared about 250 years later (pp. 85, 130). The advantage of breech-loading and rifling of cannons is the same as in the case of small arms mentioned above. Additionally, "the elongated projectile demanded by a rifled gun allows greater weight and capacity, thus augmenting its disruptive power, striking energy and efficiency" (Hogg, 1970, p. 80), which of course also applies to small-arms. Nevertheless, smooth-bore muzzle-loaders dominated the field until the second half of the 19th century.

### 3.4.1.5.1. Development of breech-loading, rifled artillery

In general, during the Napoleonic Wars, most cannons were neither rifled nor breech-loaders (O'Oconnell, 1989, p. 179). Carman (1955) writes that between 1789 and 1803, the "Royal Gun Factory" in Great Britain thought about artillery pieces with rifling. In 1792, a test was performed in Great Britain between cannons with and without rifling, where the ones with rifling proved to be superior (p. 51). The first reliable and meaningfully improved devices appeared some decades later. According to Carman (1955), Paixhans suggested using artillery pieces with rifling in France in 1835. In 1846, Wahrendorff and Cavalli both produced "rifled cannons of iron" that were "breech-loading" as well (p. 52). However, Greene and Massignani (1998) consider their models as "… successful, but inefficient …" (p. 49). Sardinia purchased 23 of Cavalli's cannons (Kinard, 2007, p. 222). Wahrendorff's cannons were used to some extent by some countries (Kinard, 2007, p. 223). Overall, they seem to have been on a sufficiently high level of quality already but experienced a lot of resistance by the military regarding their adoption, at least on a larger scale.

During the Crimean War, some cannons were changed by adding rifling and subsequently used with great effect, which spurred their further development (Fuller, 1998, p. 118). The next important war was the American Civil War, during which rifled cannons were used on a larger scale. Davis (1998) writes that the "Model 1857" or "Napoleon" was the most important piece of artillery during the American Civil War. It was a "smooth bore" muzzle loader made from "cast bronze". The Union started the war with just four pieces but purchased 1,157 units during the war. The production number for the South accounts to 535 units (pp. 103, 106). The mentioned war witnessed also the zenith of the development of "muzzleloaded, smoothbore artillery" (Kinard, 2007, p. 183). Concerning rifled cannons, the work of Parrot is noteworthy. He started working on cannons with rifling in 1849 (Kinard, 2007, p. 190). Davis (1998) writes that Parrott used "… a cast iron gun tube, then wrapping a red-hot band of iron around its breech." Afterwards, the stability of the cannon was meaningfully higher (p. 106). The number of produced Parrott pieces equals about 2,000 for the Union (Kinard, 2007, p. 191). His devices were muzzle-loaders, however. In Europe, the most important contributors were Armstrong in Great Britain and Krupp in Germany. Armstrong constructed cannons with rifling that were breech-loaders (Brodie & Brodie, 1973, p. 142). Hogg (1970) explains that Armstrong started constructing them in 1855 and that they were applied in 1859 by the armed forces of Great Britain. However, as they had problems with their lock at the breech, constructing them was stopped in 1864 and the existing ones used as “muzzle-loaders” (pp. 82–83).

**Meaningful events related to the development of breech-loading, rifled artillery**

1. 1835: Paixhans suggests using artillery pieces with rifling in France (Carman, 1955, p. 52).
2. 1846: Wahrendorff and Cavalli both produce “rifled cannons of iron” that were “breech-loading” as well (Carman, 1955, p. 52).
3. 1853–1856: Great Britain uses “smooth-bore guns” that were converted to rifled ones during the Crimean War (Carman, 1955, p. 52).
4. 1854: Armstrong suggests a process for producing cannon from wrought iron (Carman, 1955, p. 52). He also obtained a patent in this year for “a wrought iron rifled cannon” (Kinard, 2007, p. 223).
5. 1855: Armstrong constructs a “‘built-up’” cannon with extensions at critical areas (Carman, 1955, pp. 52–53). He also presents “a 3-pounder breechloader” (Kinard, 2007, p. 224).
6. 1858: Armstrong’s “3-pounder breechloader” is adopted by Great Britain (Kinard, 2007, p. 224).
7. 1859: Armstrong’s design of a breech-loader with rifling introduced in Great Britain for the navy (Brodie & Brodie, 1973, p. 142).
   1859: Krupp begins to work on “breech-loading mechanisms” (James, 2012, p. 58).
8. 1866: Prussia gets rid of old artillery models and buys steel cannons with rifling that were breech-loaders produced by Krupp instead (Boot, 2007, p. 143).

### 3.4.1.5.2. Full-scale application of breech-loading, rifled artillery

As mentioned above, rifled pieces were used during the Crimean War already. Austria acquired artillery pieces with rifling made of bronze that were muzzle-loaders after the Franco-Austrian War, which however could not make good for the advantage of Prussian infantry weapons over the Austrian infantry weapons during the Austro-Prussian War, even though the Prussians still had to a meaningful extent artillery pieces that were neither rifled nor breech-loading (Boot, 2007, pp. 129–130). As explained above, rifled pieces by Parrott were used during the American Civil War. During the Franco-Prussian War, the cannons used by Prussia, “breech-loading guns”, were technically on another level than the ones used by France, which were “muzzle-loading” (Gudmundsson, 1993, p. 1). However, also the tactical use of them was better (Kinard, 2007, p. 227). Overall, the armed conflicts at least since the late 1850s witnessed to some extent the use of rifled breech-loaders or at least rifled guns. In 1886, Great Britain abandoned muzzle-loaders (Carman, 1955, p. 53).

#### 3.4.1.5.3. Conclusion regarding breech-loading, rifled artillery

The development of this innovation was protracted and interrupted. After the pioneers Wahrendorff and Cavalli had produced and sold some of their devices in 1846, rifled guns were to some extent used during the ensuing conflicts. They were met with reservation, however. The production of rifled breech-loaders was halted in Great Britain in 1864 after Armstrong had started to produce them in the 1850s and they were only readopted in the 1880s. Nevertheless, they played a role in conflicts ever since the 1850s that should not be neglected. It seems fair to accept the year 1846 for this innovation, as the reluctant adoption reflects rather reservation by the military. Overall, this innovation can be categorized as a slow rise to full-scale application.

### 3.4.1.6. Cylindro-conoidal bullet

The cylindro-conoidal bullet is a projectile that is not ball-shaped but the lower part is shaped like a cylinder, while the tip is conic. Before the cylindro-conoidal bullet was used, loading a rifle was exhausting and time-consuming. A variety of designs of the cylindro-conoidal bullet appeared over time with many different shapes of the tip, including ones that were not conic. Many alterations were of little use however (Rüstow, 1971, p. 64). Regarding definitions of used terms, the following has to be mentioned: the Minié rifle in the narrower sense describes a rifle developed by Minié, which uses Minié balls. In a wider sense it describes also other models, which use the Minié ball like the models Enfield rifled musket or the Springfield rifled musket. The introduction of the rifle using the Minié ball enabled quick loading of rifles in general, which rendered smooth-bore muskets obsolete (Rüstow, 1971, p. 26). The accuracy of Minié rifles is much higher than the one of smooth-bore muskets, while also the impact is still high even on large distances (Rüstow, 1971, pp. 74, 80).

#### 3.4.1.6.1. Development of the cylindro-conoidal bullet

Fuller (1998) writes that Norton invented the "cylindro-conoidal bullet" in 1823 (p. 112). According to Pauly (2004), Norton's projectile was uncomplicated to load, as its caliber was smaller than the one of the rifle barrel. Furthermore, it had a hollow bottom, which lead to an expansion during the shot and pressed the outer parts against the rifled barrel. Greener's 1836 projectile was almost identical; it had "… a small tapered piece of wood" at the bottom, where it was also hollow. The wooden part moved into the hollow part of the projectile when the shot was fired, which had the same effect as Norton's hollow part. Neither Norton's nor Greener's design found large-scale application however. Another fate was destined for the model suggested by Minié in 1849. In contrast to Greener's design, it was not a ball-shaped projectile but "'cylindroconoidal'". Additionally, it had "rings" at the sides and the sides could be treated with fat, which further improved the usability and power of Minié's projectile. Also the Minié ball was hollow and had a metallic part at the bottom, similar to Greener's wooden device. Burton later simplified Minié's projectile by leaving away the part of metal at the bottom, which did not impair workability (pp. 73–74). Rüstow (1971) writes that from 1828 until the presentation of Minié's results, similar efforts were undertaken mostly in France that did not lead to a breakthrough like Minié's work however. The most important contributions might have been the suggested changes of the shape by Delvigne and Thierry into the direction of a cylindro-conoidal projectile (pp. 4–15).

According to Rüstow (1971), Minié used the design regarding the shape suggested earlier by Tamisier, who especially added many ring-shaped indentations. However, Minié added the conical hollow part and closed it with the "culot". The "culot" was wrought-iron and the expansion of gases during the firing of the shot drove the "culot" towards the tip of the Minié ball, leading to an expansion of the cylindrical part of the Minié ball. Through the expansion, the rifling of the barrel made the Minié ball spin as desired. As the diameter of the Minié ball was somewhat smaller than the one of the barrel, loading the Minié ball was quick and easy (pp. 11–12, 18).

The most important advantages of the Minié ball are according to Rüstow (1971): its shape enables a flat trajectory and no problems with for example tumbling occur. Furthermore, the impact of the projectile is high even on long distances, while the recoil of the rifle is manageable. Lastly, Minié balls are lighter than massive projectiles of the same size (pp. 20–24). The most important disadvantages are connected to the "culot" and the probability of malfunctions connected to it like the case when it separates from the projectile (Rüstow, 1971, pp. 29–32). Several modifications and improvements of the original Minié ball appeared in the following years in different countries, the most important designs worked even without “culot” (Rüstow, 1971, pp. 54–64).

**Meaningful events related to the development of the cylindro-conoidal bullet**

1. 1823: Norton invents the “cylindro-conoidal bullet” (Fuller, 1998, p. 112).
2. 1828: Delvigne develops a rifle where the bullet is deformed after loading with the ramrod, enabling the rifling of the barrel to make the bullet spin after an easy loading procedure; the system has meaningful shortcomings however (Rüstow, 1971, pp. 4–6).
3. 1836: Greener builds upon Norton’s design and adds a “… conoidal wooden plug in its base” (Fuller, 1998, p. 112). Greener’s design was not cylindro-conoidal however.
4. Since 1840: Delvigne develops the projectile further, most important is the addition of a ring-shaped indentation filled with a “fat-treated thread (own translation)”, which kept the bore clean and enabled easy gliding of the projectile (Rüstow, 1971, pp. 10–11).
   Minié works on the projectile and changes the shape of the tip from “sheer conical (own translation)” to “ogival (own translation)” (Rüstow, 1971, p. 11).
   Tamisier adds several ring-shaped indentations, which make the cylindric part lighter and make it prone to the aerodynamic drag; the result is a flatter trajectory and it gives the projectile arrow-like characteristics (Rüstow, 1971, pp. 11–12).
5. 1849: “French captain Claude-Etienne Minie [sic!] presents a cylindroconoidal-shaped expanding rifle bullet that quickly becomes popular in many countries” (Pauly, 2004, p. XVIII).
6. Since 1852: Neindorff modifies the Minié ball, his constructions include one that works without “culot” and one with a “culot” made of paper (Rüstow, 1971, pp. 54–59).
   Since 1852: The “Enfield-Pritchett-Rifle” is developed, Pritchett designs a corresponding alteration of the Minié ball (Rüstow, 1971, pp. 61–64).
   The mentioned rifle becomes later known as the Enfield rifled musket.

### 3.4.1.6.2. Full-scale application of the cylindro-conoidal bullet

Many countries adopted Minié rifles quickly. According to Rüstow (1971), France equipped four regiments with the Minié rifle already in 1849. In the following years, Great Britain, Spain, Belgium and many German states followed suit (pp. 33–54). Regarding the countries in focus of this dissertation, Great Britain and the USA, the following applies:

Great Britain adopted the Minié rifle and produced 28,000 units in 1853 (Rüstow, 1971, p. 34). Pauly (2004) explains that in 1853 the "'Enfield Rifled-Musket'" was developed and subsequently become service rifle of the army of Great Britain. The caliber of the bore was .577 and the related ammunition a Minié ball caliber .575 (p. 75). After the Crimean War, in Great Britain modern production processes based upon the use of machines as developed in the USA set in as well (O'Connell, 1989, p. 192). Subsequently, Great Britain produced 250,000 Minié balls as well as 200,000 "finished cartridges" daily (Hogg, 1963, pp. 792–793; as cited in O'Connell, 1989, p. 192).

The USA opted for the "Springfield Model 1855" rifle in 1855 (Pauly, 2004, p. XVIII). This model used the Minié ball already. The ignition system developed by Maynard was unsatisfactory and therefore the "Springfield Model 1855" was replaced by "Springfield Model 1861" (Pauly, 2004, pp. 84–85), which also used the Minié ball. Davis (1998) writes that particularly the „Union Army" relied upon the different models of the „U.S. Springfield rifle" during the American Civil War. They bought 1,472,614 of them and additionally 428,292 Enfield rifles, which taken together amounts to 75% of all long guns bought by the „Union Army" (p. 54).

### 3.4.1.6.3. Conclusion regarding the cylindro-conoidal bullet

Even though the roots of the cylindro-conoidal bullet lie in the year 1823, the true innovation that had a meaningful impact afterwards occurred in 1849 only. It is interesting to see that until 1855, Great Britain, the USA, as well as many other countries had adopted the Minié ball already. Therefore, its rise to full-scale application came quickly and qualifies as a paradigm change. Regarding the question of the impact of the cylindro-conoidal bullet, Fuller (1998) argues that it "… caused the rifle to become the most deadly weapon of the century" (p. 113).

### 3.4.1.7. Ironclad, screw-driven steamer

The ironclad can be defined as "… any vessel substantially protected with iron plates, principally on the vertical surfaces" (Gardiner & Lambert, 1992, p. 184). However, a variety of improvements in shipbuilding took place during the 19th century. Van Creveld (1991) mentions improvements in artillery, the emergence of steam power as well as the availability of "iron and steel" for the construction of ships (p. 199). To take into account the most important improvements, which meaningfully influenced naval warfare and shipbuilding afterwards, the ironclad, screw-driven steamer is chosen as the representative groundbreaking innovation. Ironclads superseded vessels made of wood and were afterwards superseded by ships made completely of steel (Epstein, 2014, p. 6). It becomes clear quickly that the factors that enabled the meaningful changes regarding naval vessels are closely related to the technological reality of the Kondratieff cycle.

#### 3.4.1.7.1. Development of the ironclad, screw-driven steamer

In 1815, Fulton constructed the "*Demologos*", which was the first battleship propelled by "the steam engine" (Canney, 1993, p. 1). In 1836, Smith patented the "screw propeller" and Ericsson the "contra-rotating propeller" (Gray, 2004, pp. 76–77). During the decade after 1850, the "the wooden screw steam warship" played a meaningful role as it enabled unprecedented operations (Lambert, 1992b, p. 38). At the same time, it became clear that vessels for war purposes propelled by sails were outdated (Lambert, 1992b, p. 41). The French "Gloire" was the "world's first seagoing ironclad", however it had deficiencies, for example was the use of wood for building it not optimal (Lambert, 1992c, pp. 53, 60). As Lambert (1992c) writes was the reaction by Great Britain the "Warrior", which was constructed in 1860, the "first iron-hulled seagoing ironclad" (pp. 54–55, 60). According to Lambert (1992c), it was more than that:

> *Warrior* summarised everything that had taken place since 1815 in one rounded package. Powered by steam, built with scientific precision (in comparison to wooden shipbuilding at least) of iron, armed (partly) with rifled breech-loading guns, protected by solid wrought iron plate 4 ½ in thick and powered by the largest set of marine engines yet built, with sail reduced to an auxiliary role. For the next century, her type would develop and prosper. (p. 58)

Worth mentioning are the effective operations of the "ironclad" "*Virginia*" and especially the encounter with the "*Monitor*", also an "ironclad", in 1862 during the American Civil War (Still, 1992, p. 72). Brown (1992) writes that the vessels of the

"Devastation *class*" were another meaningful step in the development as they were "*The first mastless, seagoing turret ships* , …". They were constructed in 1871 and 1872 (pp. 81–82, 94).

**Meaningful events related to the development of the ironclad, screw-driven steamer**

1. 1802: Symington constructs the first practical boat propelled by steam (Brodie & Brodie, 1973, p. 155).
2. 1815: The "*Demologos*" by Fulton is the first battleship propelled by "the steam engine" (Canney, 1993, p. 1).
3. 1830: "By 1830 the steam warship had been accepted in the major fleets, …" (Lambert, 1992a, p. 14).
4. 1835: "Nemesis" is constructed, which was "*the first operational iron warship*" (Lambert, 1992c, p. 47).
5. 1836: Ericsson presents a naval vessel propelled by a screw in Great Britain (Brodie & Brodie, 1973, p. 156). Smith patented the "screw propeller" in the same year and Ericsson the "contra-rotating propeller concept" (Gray, 2004, pp. 75–77).
6. 1839: First test of the "*Archimedes*", which was "the first seagoing screw vessel" (Lambert, 1992b, p. 32).
7. 1843: Stockton and Ericsson construct the "*Princeton*", which was the first battleship propelled by a screw (Brodie & Brodie, 1973, p. 156).
8. 1850: "…the Royal Navy had accepted that the sailing warship was dead" (Lambert, 1992b, p. 41).
9. 1859: Construction of the "Gloire" in France, which was the "world's first seagoing ironclad" (Lambert, 1992c, p. 60). It had meaningful deficiencies, however (Lambert, 1992c, p. 53).
10. 1860: Construction of the "Warrior" in Great Britain, which was the "first iron-hulled seagoing ironclad" (Lambert, 1992c, p. 60).
11. 1862: Encounter of "*Merrimac"* [sic!] and "*Monitor*", which was "the first trial between ironclads" (Fuller, 1998, p. 115).

### 3.4.1.7.2. Full-scale application of the ironclad, screw-driven steamer

Already the "horizontal firing shell gun" by Paixhans constructed in 1824 made clear that the time of ships made of wood for war purposes was coming to a close (O'Connell, 1989, p. 193). This became evident during the "battle of Sinope" in 1853, during which the Russian forces destroyed the vessels of the forces of Turkey (Fuller, 1998, p. 114). Keegan (2010) mentions that on 8th March 1862 the "*Merrimack*" [also called Virginia] destroyed "two large wooden warships (own translation)". The remaining vessels were able to escape and on the next day, the "*Monitor*" and the "*Merrimack*" fought without being able to destroy each other. 9th March 1862 was the day the time of "wooden warships (own translation)" had ended (pp. 197–198). Fuller (1998) even evaluates: "Metaphorically, on March 9, 1862, the wooden fleets of the world were sunk in Hampton Roads" (p. 115).

As happens often when groundbreaking innovations are used in battle against until then state-of-the-art equipment, casualties were unequally distributed on 8th March 1862. The Union had 300 dead soldiers and 100 injured ones, while the South had no one dead and only ten injured (Kinard, 2007, pp. 207–208). Greene and Massignani (1998) explain that the expression "'battleship'" replaced "'ironclad'" and the latter was used as "a historical term" afterwards. They provide the following evaluation: "The ironclad had shown itself to be the revolutionary weapon system which affected the course of history and technology, …" (p. 384).

### 3.4.1.7.3. Conclusion regarding the ironclad, screw-driven steamer

As shown above, the development of warships during the 19th century was fragmented and consisted of many different improvements. The Warrior of 1860 is the most important landmark, however. The year 1860 is therefore chosen as the year of the groundbreaking innovation ironclad, screw-driven steamer. Two years later, it became clear that the time of wooden naval vessels was over abruptly. This innovation therefore classifies as a paradigm change.

### 3.4.1.8. Cartridge case

Shields (1954) writes that early "cartridges" were made of "paper", which was a change for the better against earlier times. However, they still had drawbacks (p. 90). A cartridge in this broader sense, which enabled an efficient loading process, was for example used for the above-discussed "Brown Bess" (Held, 1970, pp. 111–112) or the Minié rifle (Rüstow, 1971, pp. 19–20).

### 3.4.1.8.1. Development of the cartridge case

The name of the inventor Pauli is at times also spelled Pauly. Ford (1999) writes that Pauli constructed an early model around 1810, which however suffered from the fact that the "percussion cap (own translation)" was not available at that time (p. 8). Pauly

(2004) mentions that the merit of Pauly was the idea to combine the “cartridge” with the explosive usually contained in the primer. Besides paper, he used metal for his “cartridge” as well, which helped to reach a high level of gas-tightness during firing already. Furthermore, his design had similarities to “‘center-fire’ cartridges”, as the load priming the main charge was located in the middle of the bottom and ignited by a small stick. The breech-loaders he constructed utilizing his cartridges became never very popular, however (pp. 94–95). According to Pauly (2004), another variant of a “cartridge” was the one used by the “‘needle gun’” of Dreyse. The priming charge was located behind the projectile and followed by the gunpowder. The long needle was necessary to reach the priming charge for ignition (p. 95). An early “pin-fire cartridge” was the design by Lefaucheux that appeared approximatively in 1836 (Shields, 1954, p. 92). Held (1970) writes that in 1846, Houiller patented a similar design. It consisted of a metallic cylinder with a closed bottom; the projectile was attached at the opposite site. Above the bottom, a small stick reached out of the cylinder. The cock of a gun using his design pushed the small stick down, which detonated the primer that ignited the main charge. It was “… the world’s first self-igniting, self-contained cartridge, complete with one absolutely essential feature of modern metallic cartridges: the *expansive case*” (p. 184). Another interesting design was the one by Hunt, as Pauly (2004) writes. It consisted of a projectile being partially hollow at the bottom, while the hollow part contained the main charge. A plate made of metal trapped the bottom and contained a small opening for ignition. A patent regarding the mentioned cartridge called “‘Rocket Ball’” dates from 1848. Somewhat later, Smith and Wesson improved Hunt’s design by inserting a device similar to a percussion cap into the hole at the bottom (p. 97). Flobert constructed his cartridge design in 1845, which essentially is “a copper cartridge with inserted percussion cap and bullet (own translation)” and is still used (Gartz, 2007, p. 115). Smith and Wesson further improved the design by Flobert by adding gun powder into the cartridge to enhance the power of it, they came up with the “.22 rimfire” as well as the “.32 rimfire” (Shields, 1954, p. 94). Pauly (2004) adds that the patent by Smith and Wesson regarding the “rimfire cartridge” dates from 1860. It contains the primer equally distributed in the “rim” (p. 98). However, rimfire cartridges did not get the meaning centralfire cartridges received over time.

Shields (1954) explains that the “.50-70” was “the first center-fire round used in the United States Army …”, used with the 1866 modification of the Springfield and in use to 1873 (p. 95). According to Ford (1999), Boxer constructed the first modern “cartridges (own translation)” in 1866 and Berdan in 1868. However, only “precise mass production (own translation)” brought later on an acceptable level of quality, as especially Boxer's early design was prone to malfunction. Berdan contributed meaningfully to the development of the expansive cartridge as he suggested, "… that the anvil for the primer could be a part of the cartridge and that the cartridges could be lathed from solid material and then be fitted mechanically (own translation)". Models based on the above-mentioned designs were also constructed in Europe and became adopted quickly (pp. 9–10). The final designs of both developers are still in use today. One of the main advantages of the design by Boxer is explained by Reynolds (1960): "When fired, the case unrolled slightly under pressure of the explosion–effectively sealing the chamber–and slight contraction on release of gas pressure permitted easy extraction of the empty case (pp. 18–19)". This is also true for the design by Berdan.

**Meaningful events related to the development of the cartridge case**

1. 1836: "*Needle gun*" patented by Dreyse (Held, 1970, p. 184).
2. 1845: Flobert constructs his design (Gartz, 2007, p. 115).
3. 1846: Houiller patents the "*pinfire cartridge*" (Held, 1970, p. 184).
4. 1848: Hunt gets a patent for his "'rocket ball'" (Pauly, 2004, p. 97).
5. 1858: "… rimfire revolvers and repeating rifles were being manufactured in all industrialized nations" (Held, 1970, p. 184).
6. 1860: Smith and Wesson get a patent for their design of the "rimfire cartridge" (Pauly, 2004, p. 98).
7. 1866: Boxer constructs his model (Ford, 1999, p. 9).
   1866: The armed forces of the USA introduce the ".50-70" (Shields, 1954, p. 95).
8. 1868: Berdan constructs his model (Ford, 1999, p. 9).

**3.4.1.8.2. Full-scale application of the cartridge case**

The situation in Great Britain can be described as follows: Pauly (2004) mentions that in 1864, Great Britain decided to convert the existing Enfield rifle to a breech-loader (p. 106). The year the conversion suggested by Snider for the Enfield was accepted is 1867 (Reynolds, 1960, p. 18). Afterwards, all meaningful models used cartridges in the modern sense until today.

The situation in the USA was as follows: Shields (1954) explains that the ".50-70" was "the first center-fire round used in the United States Army …", used with the 1866 modification of the Springfield and in use to 1873 (p. 95). Afterwards, also in the USA all meaningful models used cartridges in the modern sense until today.

### 3.4.1.8.3. Conclusion regarding the cartridge case

As can be seen, the development of the cartridge case was a drawn-out process with many interesting but not satisfying steps. The USA introduced the .50-70 in 1866. The year 1866 is therefore the year the groundbreaking innovation cartridge case appeared. Also the conversion of the Enfield in Great Britain using centralfire cartridges occurred almost instantaneously. The emergence of this innovation qualifies as a paradigm change, which is further supported by the fact that the most important military powers of the time adopted the cartridge case almost instantly as well. The metallic cartridge case is in use until today, which makes it an extremely long-lasting innovation.

### 3.4.1.9. Torpedo

Gartz (2007) mentions early descriptions of devices that have some similarities to torpedoes. For example, da Fontana wrote on such devices early in the 15$^{th}$ century, Al-Rammah did so more than 100 years earlier already (p. 84). Desaguliers and Horsay understood the possible potential of torpedoes for sinking a vessel in 1730 already (Gartz, 2007, p. 86). As the meaning of the term torpedo has changed over time, a definition is necessary:

> Until the 1860s, the word torpedo did not mean what it means today. It referred to either floating bombs that would now be known as mines … , or what are now called spar torpedoes (essentially a bomb attached to the end of a long pole projected from the bow of a warship). The modern torpedo, by contrast, is self-propelled and is therefore sometimes referred to as a fish or automobile torpedo. (Epstein, 2014, p. 3)

### 3.4.1.9.1. Development of the torpedo

Luppis of Austria learned about the sketchy suggestion of an Austrian soldier regarding a device with some similarities to a torpedo after 1860 and developed his own design of it (Gray, 1975, p. 48). In 1864, he met Whitehead and presented his design, which the latter considered unsatisfactory however (Gray, 1975, pp. 49–50). In 1866, Whitehead’s design had reached an advanced stage already and the military of Austria examined it at that time (Gray, 1975, pp. 61–62). Whitehead was perhaps the most important constructor of torpedoes over many decades (Gray, 2004, p. 11). His device can be described as follows:

> It was a prototype of the modern weapon, with depth control achieved through a hydrostatic valve and pendulum balance, and with propulsion provided by a

> small reciprocating engine working by compressed air. Later a gyroscope was introduced to control the rudder, which greatly increased directional accuracy. (Brodie & Brodie, 1973, p. 165)

A further important development was to employ two "propellers" that moved in opposite directions (Gray, 2004, p. 9). This helped to stabilize the torpedo while traveling in the water. Epstein (2014) explains that Great Britain's navy tested the model by Whitehead in 1870 and Whitehead improved his design over the next decades (pp. 4–5). By 1880, Whitehead's products were dominant on a global scale (Gray, 1975, p. 120). In 1898, the navy of Great Britain adopted Whitehead's "gyroscope", which was gradually improved afterwards and augmented the possible distance covered (Epstein, 2014, pp. 53, 57, 61). In fact "torpedoes" had a greater reach than naval cannons afterwards (Epstein, 2014, p. 62). The ensuing problems led to a new type of military ship, the "destroyer" that should eliminate vessels delivering "torpedoes" (Epstein, 2014, pp. 62–63). The navy of Great Britain introduced the "wet superheater" by Hardcastle in 1908, which augmented velocity as well as reach (Epstein, 2014, pp. 116–119, 132).

The USA used the "Howell" for a while, which deviates as it was powered by a "flywheel" (Campbell, 1992, p. 167). Its meaning was rather limited, though.

**Meaningful events related to the development of the torpedo**

1. After 1860: Luppis learns about the sketchy suggestion of an Austrian soldier regarding a device with some similarities to a torpedo (Gray, 1975, p. 48).
2. 1864: Luppis and Whitehead meet (Gray, 1975, p. 49).
3. 1866: Whitehead presents his first working model (O'Connell, 1989, p. 220). It still had defects, however (Gray, 2004, p. 9).
4. 1868: Whitehead develops a well-enigineered device for depth control of the running torpedo (Gray, 1975, pp. 67–71).
5. 1870: Naval forces of Great Britain test the design by Whitehead (Gray, 1975, pp. 14–23).

   1870: Navy of Great Britain starts purchasing Whitehead's "torpedoes" (Epstein, 2014, p. 4).

   1870: Howell constructs his design, which was powered by a "flywheel (own translation)" (Gray, 1975, pp. 119–120).
6. 1877: First use of the new weapon "in combat (own translation)" (Gray, 1975, pp. 104–106).

#### 3.4.1.9.2. Full-scale application of the torpedo

Epstein (2014) explains that it brought changes regarding strategy of naval warfare but also on a tactical level. Concerning the first, the new weapon put "expensive capital ships" severely at danger and made it difficult to block enemy access to the sea. On the tactical level, the "close order" that was common practice put the ships also at severe risk by the new weapon (pp. 10–11).

The meaning of the new weapon was high during the battle of Tsushima, which was fought in 1905 during the Russo-Japanese War (van Creveld, 1991, p. 205). Long-range deployment of it was not very efficient yet, however (van Creveld, 1991, p. 208). The Battle of Jutland is of special importance to naval warfare for a variety of reasons. Essentially, it was an encounter with an indecisive outcome. However, as O'Connell (1989) argues "… twenty tiny boats firing torpedoes had chased the entire English fleet of the field at the critical moment". The meaning of battleships was meaningfully reduced ever since and furthermore had Great Britain lost its predominance on the high seas (p. 259). Furthermore, the below-mentioned regarding full meaning of the submarine applies as well, as it depended heavily on the torpedo during the period under analysis. Gray (1975) mentions that regarding "Whitehead's factory in Fiume (own translation)", 1,456 units had been distributed by 1881, while the number of produced units for the period 1875–1917 was 12,000 (pp. 121, 216).

#### 3.4.1.9.3. Conclusion regarding the torpedo

Even though a large amount of torpedo designs emerged (Gray, 2004), the most important was the one by Whitehead suggested in 1866 and meaningfully improved in 1868. Even though it was not perfect yet, it seems acceptable for dating the groundbreaking innovation torpedo in the year 1866. The lag until acceptance was four years for Great Britain. It spread afterwards, having a meaningful impact on naval warfare until today. It is categorized as an innovation with a slow rise to full-scale use because its full potential became clear during the following decades only.

#### 3.4.1.10. Smokeless powder

Pauly (2004) explains that before the time smokeless powder was available, black powder was the usual propellant. Black powder is a mixture "… of saltpeter, sulphur, and charcoal …" and was used for more than half a millennium. Its origin might lie in China (pp. 10, 111). An improvement occurred around the year 1520, when it became clear that its burning characteristics improved when it was rather granulated than finely milled (Brodie & Brodie, 1973, p. 52).

Armstrong (1982) writes that the advantage of "smokeless powder" is that due to the missing fume, the soldiers have better sight and do not display their location when shooting. Furthermore, it pollutes the weapon much less than gunpowder, reducing the probability of malfunction. Moreover, the nature of the burning process is much more favorable than in the case of gunpowder (pp. 75–76). The speed of the reaction after being ignited is higher compared to black powder; also is the efficiency of the reaction meaningfully increased (Pauly, 2004, p. 112). One further advantage of "smokeless powders" is that depending on the shape of the pieces of powder, different burning characteristics can be produced (Shields, 1954, pp. 140–141).

**3.4.1.10.1. Development of smokeless powder**

Carman (1955) mentions two meaningful developments preceding Vielle's work: Schönbein made "'guncotton'" in 1845 from "nitric acid" and "cellulose". In 1865, Schultze introduced a compound with "gelatine", enabling a much more even burning process (p. 163). According to Gartz (2007), it was difficult to use "guncotton (own translation)" early on because it at times detonated impulsively. Abel developed a procedure in 1862, which enabled the elimination of residues of the production process and could produce a stable propellant. However, "guncotton" could damage firearms (pp. 128–132). According to Pauly (2004), Vielle produced a superior explosive in 1884, "'Powder B'":

> Vielle's particular formula was based on gelatinized nitrocellulose mixed with ether and alcohol. The mixture was rolled into flat sheets, dried, and cut into small flakes or granules. These could be loaded into a cartridge just like gunpowder and similarly ignited by fulminate. (pp. 111–112)

Pauly (2004) writes that not only Vielle but also Nobel produced "'smokeless' powder". All of them, also Vielle's product, are not entirely smokeless however (pp. 111–112). Important is also the development of smokeless explosives related to nitro-glycerin. Carman (1955) describes that Sobrero found "nitro-glycerin" in 1846. Nobel produced it from 1862 on. Nobel developed "'dynamite'" in 1867 by adding "Kieselguhr [sic!]". He also developed "'blasting gelatine'" by mixing "nitro-cellulose" and "nitro-glycerin". His product "'ballistite'" emerged later, which is a form of improved "'blasting gelatine'". A similar explosive is "'cordite'" (p. 164). Nobel developed "blasting gelatine (own translation)" in 1875 and patented "'ballistit'" in 1887, it was similar to Vielle's product but more powerful and therefore designated for use by the artillery (Gartz, 2007, pp. 124, 141). Hogg (1970) adds that

Great Britain developed a similar propellant and Dewar and Abel patented "cordite" in 1889 (pp. 140–141).

**Meaningful events related to the development of smokeless powder**

1. 1846: Schönbein makes "'gun cotton'" from "nitric acid" and "cellulose" (Carman, 1955, p. 163).
   1846: Sobrero finds "nitro-glycerin" (Carman, 1955, p. 164).
2. 1865: Schultze produces a compound with "gelatine" enabling a much more even burning process (Carman, 1955, p. 163).
3. 1867: Alfred Nobel patents "'dynamite'" (Gartz, 2007, p. 123).
4. 1884: Vielle finds "Powder B" (Pauly, 2004, p. XIX).
5. 1887: Nobel patents "'ballistit'" (Gartz, 2007, p. 141).
6. 1889: "… the armies of all major powers had adopted small-caliber rifles using smokeless powder" (Shields, 1954, pp. 139, 144; as cited in Armstrong, 1982, p. 91).
   1889: Abel and Dewar patent "cordite" (Hogg, 1970, p. 141).
   1889: The army of Italy starts using "'ballistit'", making it the earliest adaptor (Gartz, 2007, p. 141).

**3.4.1.10.2. Full-scale application of smokeless powder**

Pauly (2004) writes that France adopted the "Lebel rifle" in 1886, which was revolutionary regarding the cartridges used. The caliber was reduced to 8mm from the usually used 11mm and the powder charge consisted of the smokeless powder developed by Vielle instead of black powder. The result was that the speed of the projectile while leaving the barrel was double the speed of the 11mm projectiles being driven by gunpowder (pp. 111, 113). Walter (1993) mentions the year 1887 for the introduction (p. 115), however. About 4,000,000 units were produced in the period 1886 to 1917 (Pauly, 2004, p. 113).

The application of smokeless powder for rifles in Great Britain can be described as follows: The "MkI Cordite .303 cartridge" was adopted in 1890 (Walter, 1993, p. 118). Reynolds (1960) gives the year 1891 for adoption of the very cartridge, calling it the introduction of "the first British smokeless rifle cartridge" (p. 30). It can be concluded that Great Britain used cordite as a propellant ever since presumably 1891, as it seems to be the correct year.

Regarding the use of smokeless powder in the USA, the following applies: The ".30-40 Krag" was the first one being filled with the new propellant used by the armed forces of the USA (Shields, 1954, p. 147). It was used by the "Krag-Jørgensen" (Walter, 1993, pp. 106–108), which was introduced in 1892. It marks the year the USA introduced smokeless powder, a year later than Great Britain.

**3.4.1.10.3. Conclusion regarding smokeless powder**

The year for the innovation smokeless powder is 1884, as Vielle's product was the first reliable one that was also used for the ammunition of the French service rifle, the Lebel of 1886. The introduction as a propellant took only two years in France, seven in Great Britain and eight in the USA. This innovation can be regarded as a paradigm change.

**3.4.1.11. Machine gun**

When looking at the first appearance of the machine gun, the question arises what qualifies as the first machine gun. Concepts of it are around for centuries already. Ellis (1986) argues that the so-called "*ribauldequins*", which might have appeared in the 14th century can be seen as a first attempt to enhance firepower through the bundling of many "barrels". However, they had many disadvantages like all other similar devices that appeared over the next centuries (pp. 10–16). Puckle patented another early model with some similarities to a revolver in 1718 (Carman, 1955, p. 80).

**3.4.1.11.1. Development of the machine gun**

True machine guns in the sense that they can provide sustained fire appeared after 1860 only with models like the Gatling gun, Gardner gun or Mitrailleuse (all crank operated, the Mitrailleuse appeared some years earlier), Nordenfelt gun (lever operated) or finally the Maxim machine gun and the one by Browning (both fully automatic). Ellis (1986) stresses the fact that almost all meaningful constructors of machine guns came from the USA. He argues that there are many causes why the USA was the place where the machine gun was developed. One point is the fact that mechanization started there on a large scale, as labor was scarce and had to be substituted by machines. Furthermore, a large number of craftsmen that might have been able to slowly produce the weapons needed by the state, as in Europe, did not exist. A solution based upon mechanization was therefore inevitable (pp. 21–23, 41).
From the area of crank operated guns, the "*Gatling gun*" was the most important one (Ellis, 1986, pp. 26–31). Armstrong (1982) even argues that the "model 1866 Gatling gun" was by far the best model available until the appearance of Maxim's device almost two decades later (p. 46). Therefore, the analysis of crank operated machine

guns below focuses on the Gatling gun and leaves aside marginal models, which for example never saw large-scale production. According to Armstrong (1982), Gatling's design of 1862 consisted of a bundle of six rotating "barrels"; a winder induced the rotation. Gatling constructed special "cartridges" that fell into the chamber for firing and were thrown out afterwards. In the following years, Gatling optimized his design further (pp. 32, 35–36). Especially "… seamless drawn centerfire cartridges by Berdan… (own translation)" played a meaningful role regarding the upgrading (Ford, 1999, p. 15). Gatling chose the design with up to ten rotating barrels to deal with the problem of the large amount of heat originating from firing (Pauly, 2004, pp. 118–120). The principle of Gatling's model persists in modern arms like the "M61 Vulcan automatic cannon" or "Miniguns" in smaller calibers, which are capable of "6,000 shots per minute" (Ellis, 1986, p. 177). The development of new designs building upon the Gatling gun emerged after the Second World War (Ford, 1999, pp. 170–171).
More important, however, are two designs, that appeared later than the Gatling gun: the model developed by Maxim as well as the one developed by Browning. According to Ellis (1986), Maxim presented his design in 1884, which

> ... utilised the force of the recoil to operate the ejection, loading and firing mechansisms. Once the first round was fired the whole operation of the gun was *fully* automatic. (p. 33)

According to Ellis (1986), 1892 is the year in which Browning constructed his model that was gas-operated (p. 16). Pauly (2004) explains the operating principle as follows:

> This machine gun had a small hole drilled in the bottom of the barrel toward the muzzle. Some of the expanding gases driving the bullet were diverted into this opening, where they pushed down a lever that in turn opened the breech. A spring forced the arm back into position and rechambered a new round. Fresh ammunition was fed into the mechanism basically through the same belt system used by the Maxim. (p. 125)

Together with the recoil-operated Maxim model, it represents the beginning of modern machine guns, which shaped armed conflicts ever since. The two operating principles form the technical basis for the majority of modern arms (Pauly, 2004, pp. 121, 126).

**Meaningful events related to the development of the machine gun**

1. 1851–1869: Development of the mitrailleuse (Brodie & Brodie, 1973, p. 145).
2. November 1862: Gatling gun patented (Ellis, 1986, p. 26).
3. 1865/1866: enhanced model of the Gatling gun constructed (Ellis, 1986, p. 29).
4. 1866: Armed forces of the USA start using the Gatling gun (Ellis, 1986, p. 29).

5. 1867: Armed forces of Great Britain and Japan start using the Gatling gun (Ellis, 1986, p. 29).
6. 1870–1871: "*mitrailleuse*" used in the Franco-Prussian War (Ellis, 1986, pp. 63–64).
7. 1884: Maxim's design presented (Ellis, 1986, pp. 16, 33).
   The patent dates from the same year (Armstrong, 1982, p. 75).
8. 1887: The first adopter of the design by Maxim is Italy (Ford, 1999, p. 51).
9. 1889: Maxim machine gun adopted by Great Britain (Brodie & Brodie, 1973, pp. 146–147).
10. 1892: Browning machine gun invented (Ellis, 1986, p. 16).

**3.4.1.11.2. Full-scale application of the machine gun**

The machine gun was first used during the American Civil War and to some extent during the Franco-Prussian War. However, according to Ellis (1986) in the case of the Franco-Prussian War, the "*mitrailleuses*" were grouped together with the cannons and destroyed by superior artillery of Prussia before they could participate in the battle. This is at least true for the "Battle of Spicheren" and the "Battle of Wissembourg". One exception was the "Battle of Gravelotte", however (p. 64). Afterwards, it found application in mob control in the USA and for fighting in the colonies where large casualties were inflicted on the natives like during the "Battle of Omdurman" (Ellis, 1986, pp. 18, 42–44, 87).

Nevertheless, this only represents a small-scale use in comparison to what happened during the First World War, for example when looking at the number of machine guns used (only few pieces were used in the colonies) or casualties inflicted. The usage of the machine gun during the First World War shaped the appearance of the whole war (Brodie & Brodie, 1973, pp. 190–191). However, the armed forces of Great Britain as well as of the USA underestimated the meaning of it before the First World War (Ellis, 1986, pp. 68–74). Looking at the impact of the new weapon, Ellis (1986) writes "The power of the defence, and particularly the machine gun, had rendered almost nil the chances of successful frontal attack" (p. 124). Output figures provide another perspective; the representative example of Great Britain provides a better understanding for the time until the end of the First World War. Ellis (1986) writes that the time between the introduction of the new weapon and the First World War was uninteresting regarding output figures. They only started to rise meaningfully with the advent of the war. Before 1914, the production level of machine guns at Vickers for the "War Office" was about eleven pieces yearly (pp. 38–40).

Figure 11 shows the increase in output figures of machine guns produced at Vickers during the First World War. The sum of the numbers is about 71,000. According to Ellis (1986), additionally 133,196 machine guns type Lewis and 25,379 type Hotchkiss were provided to the forces of Great Britain during the same time frame, which gives a sum of almost 250,000 machine guns overall (p. 39). The USA produced meaningful amounts of machine guns as well but bought additionally 37,864 machine guns type Chauchat from France (Ellis, 1986, p. 40). The production per month overall in the USA was on average 27,270 pieces during the last months of the First World War (Ellis, 1986, p. 76).
The output figures regarding the five belligerents USA, Great Britain, Soviet Union, Germany, and Japan during the Second World War amount to overall more than 6.6 million pieces (Harrison, 2000, pp. 15–16). However, the emergence of the "tank" and a better understanding of the "machine gun" and associated tactics took away the superiority it provided during the First World War (Ellis, 1986, pp. 167–168). Nevertheless is the machine gun an important military weapon until today.

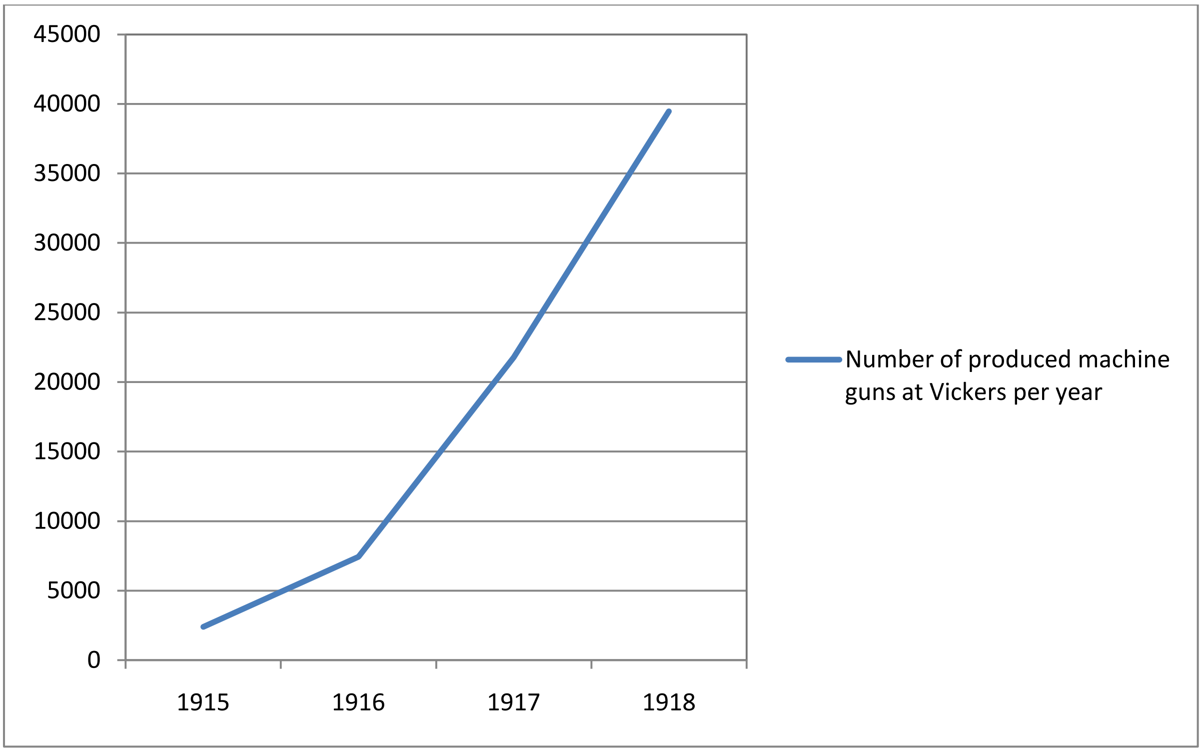


**Figure 11:** Number of produced machine guns at Vickers per year, 1915–1918.
(Own depiction, based upon Ellis, 1986, p. 39)

#### 3.4.1.11.3. Conclusion regarding the machine gun

In general, the meaning of the mentioned two models developed by Maxim and Browning and their successors was not reached by the crank or lever operated earlier models. Therefore, the year of the innovation machine gun is determined as 1884, the year the Maxim machine gun appeared. This innovation had a rather slow rise to full-scale application because it was used on a small scale in the beginning only. Moreover, its full meaning was understood during the First World War only.

### 3.4.1.12. Automobile

An early suggestion of an internal-combustion engine dates from 1794, when Street suggested such a device (Brodie & Brodie, 1973, p. 169). A model working with black powder dates back to 1680 (Fuller, 1998, p. 157). Regarding the propulsion of vehicles, early models used steam as a propellant. The crude devices constructed by Cugnot in the period 1765–1770 might have been the earliest but they had some flaws (Volti, 2006, p. 2).

#### 3.4.1.12.1. Development of the automobile

The basis of the automobile is the internal-combustion engine. According to Volti (2006), Lenoir constructed one of the more modern designs using "illuminating gas" as propellant. In 1862, he even propelled a crude car with his device. However, his device suffered from limitations and found no further use. Otto and Langen marketed a "noncompression engine" for a while before Otto constructed a motor working according to the "four-stroke cycle" in 1876, which became a success afterwards (p. 3). Otto's design was also "the first four-stroke gas-engine to be sold commercially" (Jewkes, Sawers & Stillerman, 1969, p. 57). The related diesel engine, which was developed in the 1890s works differently. Volti (2006) explains that ignition occurs due to the high pressure and temperatures that occur and they are more efficient as they work with "higher compression ratios". Among other applications, they were used to propel naval vessels and only found their way to propel automobiles and "trucks" in the 1920s (p. 76).

Regarding the automobile, the most important steps were the following: Volti (2006) writes that Benz built an early car-like vehicle in 1885, which had three wheels only. In the very same year, Daimler and Maybach propelled a device with two wheels with an internal-combustion engine, a year later one with four wheels (p. 4). Important further developments were according to Volti (2006) the "pneumatic tire" in 1888, electric ignition, an improved "cooling system" in 1901, an electric "self-starter" in

1912, and higher “knock resistance” of gas in 1923 (pp. 11–13, 33, 60). Another related development was the rise of Ford and his production methods. He constructed his first car in 1896 (Volti, 2006, p. 23). Boot (2007) writes that Ford worked with “interchangeable parts“ and the “moving production line”, enabling him to produce on a level of efficiency and cheapness that was not possible before (p. 207). The two elements of modern production methods were discussed above in the context of the interrelationship of general innovations and innovations in the area of weapons technology already.

**Meaningful events related to the development of the automobile**

1. 1859: Lenoir builds a working motor (Boot, 2007, p. 206).
2. 1862: Beau de Rochas provides the theoretical framework for the modern internal-combustion engine (Brodie & Brodie, 1973, p. 169).
3. 1876: Otto comes up with “the four-stroke internal combustion engine” (Volti, 2006, p. XIII).
4. 1885: Benz constructs a car-like vehicle (Volti, 2006, pp. XIII, 4).
   1885: Daimler and Maybach build a crude motorcycle (Volti, 2006, p. XIII).
5. 1886: Daimler and Maybach build a crude car (Volti, 2006, p. XIII).
6. 1888: Dunlop comes up with the “pneumatic tire” (Volti, 2006, p. XIII).

### 3.4.1.12.2. Full-scale application of the automobile

Fuller’s (1998) evaluation of this innovation is that it “… introduced warlike possibilities which went far beyond anything as yet accomplished by either gunpowder or steam power” (p. 134). Therefore, figures 12 and 13 represent only a fraction of the true impact. The groundbreaking innovations tank, airplane as well as submarine are also heavily dependent on the internal-combustion engine.

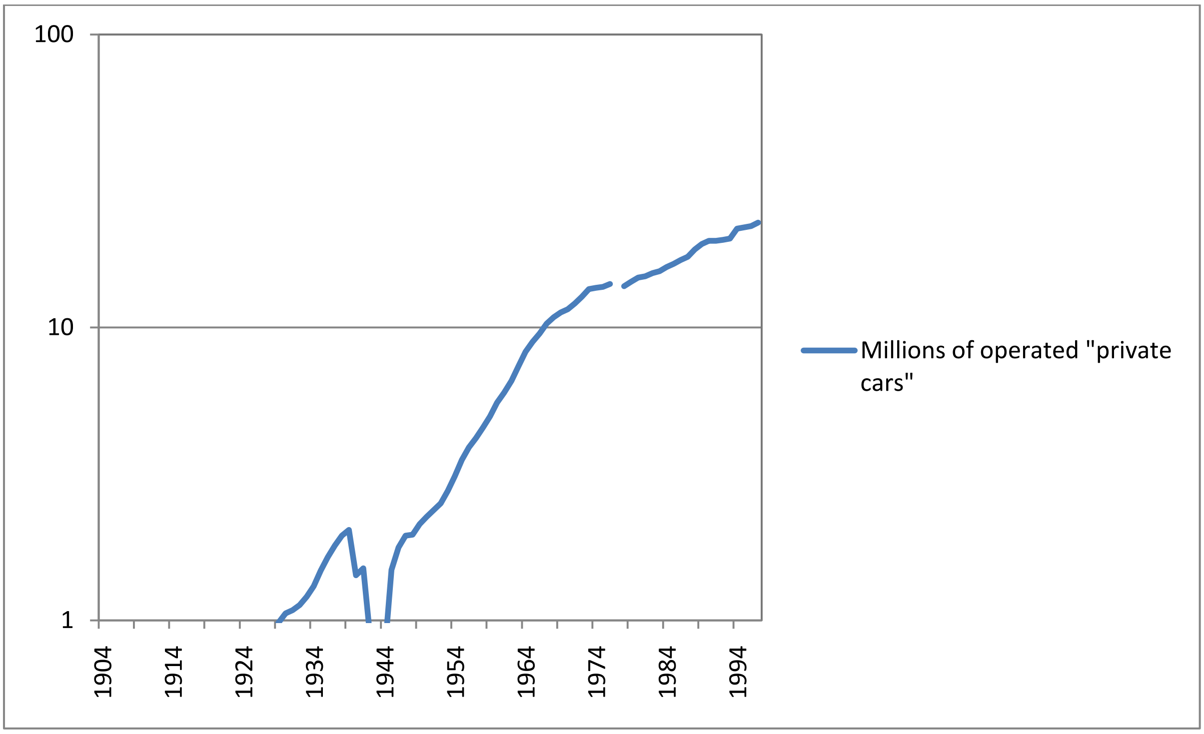


**Figure 12:** Millions of operated “private cars” in Great Britain, 1904–1997.
(Own depiction, based upon Mitchell, 2003a, pp. 738–742)

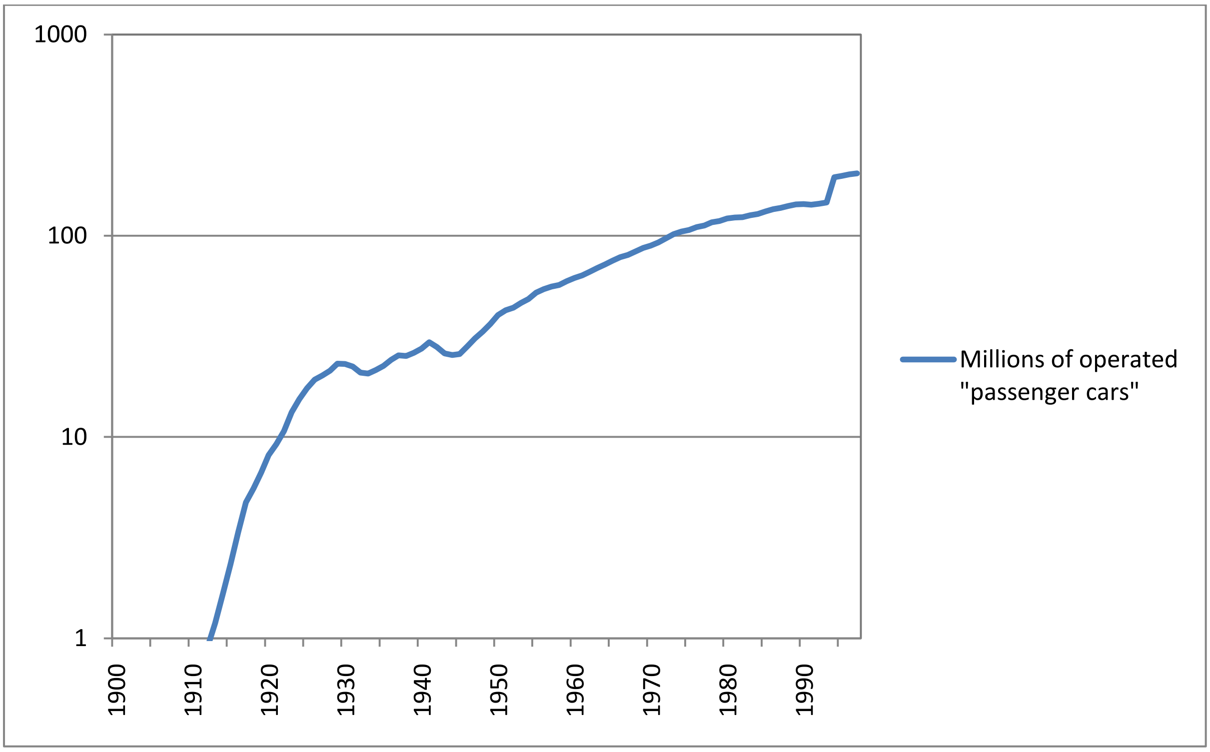


**Figure 13:** Millions of operated “passenger cars” in the USA, 1900–1990.
(Own depiction, based upon Mitchell, 2003b, pp. 588–594)

Regarding the meaning of vehicles like cars or trucks, the following applies for the time of the First World War: in France, taxis drove soldiers to the front in 1914 (Boot, 2007, p. 207). Volti (2006) adds that assignments like “transportation, scouting, courier duties, ambulance services” were fulfilled by cars. Many automobiles were commandeered for use by the military, the Allies utilized 125,000 cars of Ford’s “Model T” alone. A related phenomenon is the meaningful growth of the “trucking industry” in the USA during the First World War (pp. 44–46). Output figures rose from about 25,000 to 200,000 from 1914 to 1918 per year (Hacker, 2007, p. 66). As also mentioned in the section dealing with the airplane, manufacturing internal-combustion engines for the aircraft industry was a meaningful task during the First World War. Mainly car companies performed this task (Volti, 2006, pp. 44–45).
A similar mushrooming of output figures took place during the Second World War. Representative for the overall production efforts of the car manufacturers of the USA are the numbers provided by Volti (2006): 2,500,000 “trucks” as well as 660,000 “Jeeps” were constructed, apart from motors and military equipment (pp. 85–86). By 1939, the army of the USA was to a meaningful extent motorized (Raines, 2011, p. 241). The Second World War was dominated by motorization with “aircraft and tanks” as the main features (Kaldor, 1982, p. 58). This is also displayed by the production numbers provided in the chapters dealing with the groundbreaking innovations tank and airplane. Figures 12 and 13 support the above-mentioned with more general data regarding Great Britain and the USA. However, this should be taken with a grain of salt. As Boot (2007) writes, were just about two tenths of the German units that attacked France in 1940 to a meaningful extent motorized (p. 234).

### 3.4.1.12.3. Conclusion regarding the automobile

The year 1885 is considered as the year the innovation automobile appeared. The automobile by Benz had only three wheels but can be seen as the first automobile. It is closely connected to Nefiodow and Nefiodow’s (2014) fourth Kondratieff cycle, where the car is the basis innovation. Regarding the rise to full-scale application, the findings of this dissertation are in line with Nefiodow and Nefiodow’s (2014) claim that the car dominated the Kondratieff cycle starting in 1945. The Second World War witnessed massive car production and the car found wide application during the following decades, as figures 12 and 13 show. It seems adequate to categorize it as a slow rise to full-scale application.

### 3.4.1.13. Magazine

Early devices capable of firing many shots were mostly organ guns with many barrels attached to each other. Ellis (1986) writes that the "magazine" arose during the American Civil War and became especially meaningful during the 1880s (pp. 48, 51). Overall, a variety of magazines exists, among them tubular ones, box magazines, and drum magazines. Tubular magazines were used in the early repeaters like the Henry rifle but also in later models like the Mauser 1871/84 or the Lebel 1886. They are still used to some extent. However, box magazines are the most important ones, dominating the world of small arms and especially service rifles until today.

#### 3.4.1.13.1. Development of the magazine

Pauly (2004) explains that after 1848, Hunt developed the "'Volitional Repeater'" [the correct name is "Volition Repeater"] that was called "Volcanic Repeater" later on and was modified several times. However, it never became very reliable and easy to use. Only the design by Henry reached a high degree of perfection (pp. 97–99). Shields (1954) writes that the design by Henry was "the first magazine rifle to see anything like widespread service in the United States Army …", as 1,731 units were transferred to the armed forces. It was based upon "Hunt's Volition Repeater" and had a tube magazine (pp. 117–119). The "Spencer Magazine Rifle, Model 1865" was by and large similar (Shields, 1954, pp. 119–122). An early encounter on a limited scale between troops using "Henry rifles" and troops having no repeaters occurred in 1863 and showed the superiority of the repeater (Pauly, 2004, p. 99). Shields (1954) explains that the "Winchester Magazine Rifle, Model 1866" was a to some extent improved version of the design by Henry. It found only little application by the armed forces, however (pp. 122–126). Noteworthy is the early large-scale use of magazine rifles in an armed conflict. According to Pauly (2004), the Turks had acquired 50,000 "Winchesters" and used them with good effect during the "siege of Plevna" against Russian forces in 1877 (pp. XIX, 110). Later on, tube magazines were used for the German Mauser 1871/84 as well as for the French Lebel 1886. According to Walter (1993), "Model 1871" was introduced in 1871 and was used in meaningful quantities by various German states. "Model 1871/84" appeared in 1884 and had a "tube magazine" holding eight cartridges. About 950,000 were produced (pp. 168–170). France introduced the "Lebel Models 1886" in 1887, and the "1886/93" in 1893, about 4,000,000 of them were produced and the "tube magazine" had a capacity of eight cartridges (Walter, 1993, p. 115).

The origin of the modern box magazine lies in the year 1879. Carman (1955) writes that Lee obtained a patent in 1879 for his "box-magazine" made of metal with a capacity of five rounds, which were held under pressure from the bottom of the magazine by a "spring". His design was a major improvement of the tubular magazines available earlier on, as they were prone to cartridges being ignited while still in the magazine (p. 122). The first meaningful model to utilize the patent was the one by Mannlicher of 1886 (Reynolds, 1960, p. 25). According to Pauly (2004), it was the first model to use the "'clip'" for reloading. The "'clip'" holds a certain amount of rounds and makes reloading easier and quicker (pp. XIX, 114). The "Lee-Metford" was the first model using "removable box magazines", which is the most important design until today (Pauly, 2004, pp. 116–117).

**Meaningful events related to the development of the magazine**

1. 1860: Design by Henry patented (Shields, 1954, p. 118).
   1860: Design by Spencer patented (Shields, 1954, p. 119).
2. 1863: Superiority of "Henry rifles" proven in combat (Pauly, 2004, p. 99).
3. 1879: James Lee patents his "box-magazine" with a capacity of five rounds (Carman, 1955, p. 122).
4. 1886: "Austrian nobleman Ferdinand Ritter von Mannlicher develops a bolt-action rifle using a fast 'packet' or 'clip' reloading system" (Pauly, 2004, p. XIX). It used the "Lee magazine" (Reynolds, 1960, p. 25).
   1886: Austrian army introduces the "box-magazine" (Carman, 1955, p. 122).
5. 1887: Italian army introduces the "box-magazine" (Carman, 1955, p. 122).
6. 1888: "Britain develops the Lee-Metford bolt-action rifle, which uses a detachable box magazine" (Pauly, 2004, p. XIX).

**3.4.1.13.2. Full-scale application of the magazine**

The situation in Great Britain can be described as follows: The first model to use a magazine was the Lee-Metford. Walter (1993) writes that it was adopted in 1888; it had a "box magazine" holding between 6 and 10 cartridges depending on the model. It had some issues however. The "Lee-Enfield" followed in 1895 and had a "box magazine" holding 10 cartridges. The output figures of the most important models are approximatively 3,000,000 (pp. 118–119). "Enfield Pattern 1914" followed, which had a "box magazine" holding five cartridges (Walter, 1993, p. 62). "Rifle No. 4", which was related to the "Lee-Enfield" appeared in 1929 and reached output figures of approximatively 3,530,000 (Walter, 1993, p. 120). It can be concluded that Great Britain introduced the magazine in 1888 by adopting the Lee-Metford. In general, all meaningful subsequent service rifles used box magazines.

Regarding the USA, the following applies: According to Walter (1993), the USA introduced the “Krag-Jørgensen” in 1892, which had an “internal pan magazine” with a capacity of five cartridges. The output figures of the most important models are about 474,390 units (pp. 106–108). Walter (1993) writes that the “Springfield Model 1903” was adopted in 1903 and had a “magazine” holding five cartridges. Output figures reached approximatively 1,970,000 units. The “Model 1903A3” produced ever since 1942 reached output figures of approximatively 943,000 (pp. 264–266). Overall, the USA introduced the magazine for rifles in 1892 with the Krag-Jørgensen, even though it had no box magazine. The box magazine was introduced with the Springfield Model 1903 in 1903. Of course, the box magazine stayed in use afterwards in the USA as well.

### 3.4.1.13.3. Conclusion regarding the magazine

The tube magazine was an integral part of the Henry and Spencer repeaters and therefore ready by 1860. The devices by Hunt and his successors that preceded the models by Henry and Spencer were not well engineered enough to be accepted. However, the meaning of the tube magazine and of the mentioned repeaters did not reach the one of the box magazine, which is important until today. The year Lee’s patent of 1879 found application in Mannlicher’s model in 1886 is therefore chosen for the groundbreaking innovation magazine. The most important countries adopted designs using it as service rifles between 1886 and 1888. The time span until the beginning of a large-scale use is therefore marginal. Therefore, the innovation magazine is categorized as a paradigm change. The Krag-Jørgensen adopted by the USA with its somewhat offbeat magazine can be seen as an aberration, which played a small role only as the USA adopted the Springfield 1903 relatively quickly afterwards, using a box magazine.

### 3.4.1.14. Quick-firing artillery

The problem with cannons from early times on was that they had to be aimed again after every shot because of the kickback (Brodie & Brodie, 1973, p. 49). Quick-firing artillery solved this problem. It can be defined as follows: "… the essentials were brass cartridge case including a primer, a quick-acting breech mechanism and a mounting suitable for rapid aimed fire" (Campbell, 1992, p. 163).

#### 3.4.1.14.1. Development of quick-firing artillery

De Beaulieu suggested the "muzzle break (own translation)" in 1864 (Militärwissenschaftliche und technische Mitteilungen 58, 1927, p. 329; as cited in Linnenkohl, 1990, p. 235). They have a dampening effect on the "recoil (own translation)" (Linnenkohl, 1990, p. 234). In 1867, Siemens provided an idea to deal with the kickback utilizing a "hydraulic buffer" (Hogg, 1970, p. 107). Five years later, Moncreiff "… produced his ideas for a hydropneumatic carriage which absorbed the shock of the recoil" (Carman, 1955, p. 53). Quick-firing artillery arose during the 1880s but was limited to either very large or very little pieces, making them unsuited as "field guns" (Gudmundsson, 1993, p. 6). During the late 1880s, adequate locks for the guns appeared (Linnenkohl, 1990, pp. 116–117). Already in 1887, ten shots in less than a minute were reached with a model in Great Britain and two years later the naval forces of Great Britain adopted the first model (Campbell, 1992, p. 163). The naval forces of Italy did so during the same year, Germany followed suit in 1891 and France in 1894–1895 (Campbell, 1992, pp. 163–164). Gudmundsson (1993) mentions that regarding "field artillery", Germany equipped her army from 1896 on with the "model 1896 quick-loading 77mm gun" and a year later France introduced the "75mm quick-firing field gun" (p. 6).

**Meaningful events related to the development of quick-firing artillery**

1. 1864: de Beaulieu suggests the "muzzle break (own translation)" (Militärwissenschaftliche und technische Mitteilungen 58, 1927, p. 329; as cited in Linnenkohl, 1990, p. 235).
2. 1867: Siemens provides an idea to deal with the kickback utilizing a "hydraulic buffer" (Hogg, 1970, p. 107).
3. 1872: Moncreiff "… produced his ideas for a hydropneumatic carriage which absorbed the shock of the recoil" (Carman, 1955, p. 53).
4. Late 1880s: "Gruson-falling-block lock (own translation)" appears (Linnenkohl, 1990, pp. 116–117).

5. 1887: Ten shots in less than a minute reached with a model in Great Britain (Campbell, 1992, p. 163).
6. 1889: Naval forces of Great Britain adopt the first model (Campbell, 1992, p. 163).
7. 1898: The "'75'" is adopted, it uses a "hydraulic" device for dealing with the kickback (Hogg, 1970, p. 108).

#### 3.4.1.14.2. Full-scale application of quick-firing artillery

According to Gudmundsson (1993), the "French 75mm" was by far the best model, reaching a rate of fire of up to 30 shots in 60 seconds and remaining in position nevertheless thanks to the utilized "'long recoil'" device. It remained in secrecy for some years but after its deployment yielded great success, nearly all meaningful countries had to equip their armies with similar models (pp. 7–8). Hogg (1998) adds that its origin might lie in the 1880s, "the hydro-pneumatic recoil system" of it might have been ready by 1894. An especially new and important feature was the "trail spade". Output figures until 1918 are about 17,000. However, already by 1914, Germany, Great Britain and Austria had superior models (pp. 37–41).
Hogg (1970) explains that Great Britain developed new models of quick-firing artillery that were adopted in 1905, utilizing a "hydraulic buffer" for dealing with the kickback. They stayed in service until about 1939 (pp. 108–109). Hogg (1998) adds that Great Britain especially used the "13-pounder QF gun" as well as the "18-pounder QF gun" as "field guns". Of the latter, which was more important, the number of produced units is 1,126 until 1914. During the First World War, an additional 8,393 were produced in Great Britain and 851 in the USA (pp. 19, 21). The situation in the USA is explained by Hogg (1998, pp. 48–53) but does not add further insights.
However, as already mentioned above, quick-firing pieces were not limited to the use as field artillery but also used for naval guns. Also "howitzers (own translation)" were designed as quick-firers (Linnenkohl, 1990, pp. 83–94).

#### 3.4.1.14.3. Conclusion regarding quick-firing artillery

The year of the groundbreaking innovation quick-firing artillery is 1889, the year the naval forces of Great Britain adopted the first solid model. This innovation is an extreme example of how quickly materiel can get obsolete, as was the case when the superior French 75mm gun became known. As mentioned above, the 75mm was inferior to other models quickly as well. The quick emergence of this innovation justifies a categorization as a paradigm change. How this innovation changed the field of artillery displays the following example: the number of shots fired per German cannon was 200 during the whole Franco-Prussian War but during the First World War at times this was the daily rate of fire (van Creveld, 2008, p. 51).

#### 3.4.1.15. Submarine

Already Leonardo da Vinci described some kind of submarine (Gierschner, 1987, p. 7). An early attempt was the design by Bushnell, which dates from 1776 and can be seen as "the first successful submersible (own translation)" (Lipsky & Lipsky, 2000, p. 8). "The first submersible that destroyed an enemy ship… (own translation)" was the "Hunley", which did so in 1864 during the American Civil War (Lipsky & Lipsky, 2000, p. 8). However, truly usable devices became possible during the "Industrialization (own translation)" only (Lipsky & Lipsky, 2000, p. 7). Still, most models constructed until 1914 were rather "submersibles", which means they mostly traveled not under water but did so shortly before an engagement only (Epstein, 2014, p. 7).

##### 3.4.1.15.1. Development of the submarine

Holland's earliest model dates from 1878 (Lipsky & Lipsky, 2000, p. 98). According to Gierschner (1987), he later constructed the "Holland", which had two motors, one electric and one driven by gasoline. Furthermore, it was constructed to launch torpedoes. The armed forces of the USA adopted this model in 1900 and purchased more units. Also Great Britain constructed models of Holland's design after 1900 (pp. 60–61).

Another important landmark was the "Aigrette" that was constructed in 1903, which was "the first diesel-electric submarine … (own translation)" (Gierschner, 1987, p. 64). This kind of propulsion still dominated the field in the 1980s (Gabler, 1987, p. 65). In 1937, the first submarines equipped with snorkels were constructed (Gierschner, 1987, p. 71). Their advantage is that they can travel propelled by the internal-combustion engine even when submerged (Gabler, 1987, p. 77). The first design propelled by atomic energy was "USS Nautilus"; it sailed for the first time in early 1955 (Gierschner, 1987, p. 77). This type of submarine is able to sail submerged for a long time (Gabler, 1987, p. 83).

**Meaningful events related to the development of the submarine**

1. 1878: Holland's earliest model is constructed (Lipsky & Lipsky, 2000, p. 98).
2. 1887: Peral constructs the first model that uses "rechargeable batteries (own translation)", Zédé does so a year later (Gabler, 1987, p. 9). Peral also uses a "periscope (own translation)" for his model already (Lipsky & Lipsky, 2006, p. 70).
3. 1893: Holland starts working on the "Plunger", which had two motors already (Gierschner, 1987, pp. 59–60).
4. 1894: Lake's submarine is equipped with a crude snorkel already (Gabler, 1987, p. 77).
5. 1897: Completion of the model that later becomes "USS *Holland*" (Wilson, 1992, p. 153).
6. 1899: "*Narval*" is constructed, which is "the prototype of the submarine with a double-hull (own translation)" (Gabler, 1987, p. 9).
7. 1900: Naval forces of the USA adopt the "USS *Holland*" for service after changes had been performed (Wilson, 1992, p. 153).
8. 1901: "H.M. Submarine Torpedo Boat No. 1" is constructed, which is the first of Great Britain's armed forces and one of Holland's design (Lipsky & Lipsky, 2000, p. 50).
9. 1903: "Aigrette" that was constructed in 1903, was "the first diesel-electric submarine … (own translation)" (Gierschner, 1987, p. 64).

### 3.4.1.15.2. Full-scale application of the submarine

The new weapon played an important role regarding sinking trade vessels during the two World Wars (Boot, 2007, p. 178). Great Britain was severely affected by it during the First World War (van Creveld, 1991, p. 210). Still, the warfare against trading vessels was interrupted twice (Brodie & Brodie, 1973, pp. 182–183). Nevertheless, Lipsky & Lipsky (2006) write that "German submarines (own translation)" destroyed 5,282 to 6,394 "trading vessels (own translation)" with 11,948,500 to 12,284,700 BRT during the First World War. Furthermore, they destroyed 100 "battleships (own translation)" (p. 28). The number of sunken submarines during the First World War overall is 265 (Gierschner, 1987, p. 67).

They played an important role again during the Second World War in almost all areas.

The Japanese tonnage sunken by submarines of the USA during the Second World War amounts to 8,000,000 tons, more than 80% of total Japanese tonnage available; furthermore, Japanese imports were reduced to 60% with especially oil imports meaningfully impaired (Morison, 1963, p. 511; Spector, 1985, pp. 486–487; as cited in O'Connell, 1989, p. 293). Regarding casualties, about 2% of the personnel of the navy of the USA inflicted more than half of the maritime casualties of Japan (Morison, 1963, p. 511; Spector, 1985, pp. 486–487; as cited in O'Oconnell, 1989, p. 293). During the Second World War, the German tactic intended to bundle u-boats after enemy vessels had been spotted to augment the impact of the attack (van Creveld, 2008, pp. 134–135). According to Lipsky & Lipsky (2006), they destroyed 2,600 to 2,919 vessels with 14,232,747 to 15,600,000 tons during this period (p. 47). The number of sunken submarines during the Second World War overall is 1,137 without the ones of the Soviet Union (Gierschner, 1987, p. 76).

An important role played by submarines during the decades after the Second World War was operating as submerged and mobile SLBM launching sites. The USA owns 16 such devices propelled by atomic energy, Russia 14 (Boot, 2007, p. 422). The number of nuclear-powered submarines constructed in the USA and the Soviet Union was about 146 until the 1980s each, the number is considerable smaller for Great Britain (Gabler, 1987, p. 13).

### 3.4.1.15.3. Conclusion regarding the submarine

Van Creveld (2008) gives the year 1900 for the "first modern submarine", which could run both on gasoline as well as electricity (p. 11). This seems to be the first submarine of the USA by Holland. The year 1897 is chosen for the groundbreaking innovation submarine, as it was the year of the launching of Holland's design. Even though it was only adopted after changes had been performed (Wilson, 1992, p. 153), it is the start of the groundbreaking innovation submarine in the narrower sense. Also Great Britain adopted submarines soon.

Submarines played an important role during both World Wars and did so during the Cold War as well. The question how the innovation has arisen is a bit delicate; it seems fair to see it as a slow rise to full-scale application as the early use during the First World War was mostly performed by Germany and also rather hesitantly only.

### 3.4.1.16. Wireless communication

As the term radio relates to many different applications of radio waves, the term wireless communication is chosen. It is defined as the transmission of Morse code and voice via radio waves. The transmission of Morse code is explicitly included, as especially the early devices and the ones used at sea were rather wireless telegraphs. The ability to transmit voice arose later only.

#### 3.4.1.16.1. Development of wireless communication

The development of wireless communication was complex, as it was dependent on many observations and steps of scientific progress (Regal, 2005, p. 1). Regal (2005) explains that Loomis patented his design in 1872; he seems to have been able to make transmissions of about 18 miles, which is somewhat unclear however. In 1895, Tesla presented a crude model to broadcast “vibrations”; while Lodge was already able to use telegraphy devices without wires on distances of about 150 yards. An important figure related to the development of wireless communications is Marconi. His role is comparable to the one of Morse concerning telegraphy. Meaningful is that he could imagine ways wireless telegraphy could be used businesswise. He had constructed a similar device as Lodge by 1895 and understood the meaning of the antenna. He presented his device in public a year later. In 1899, Marconi reported on “America’s Cup” from a boat with his device. Two years later, he was even able to send a signal from Great Britain to Canada. In 1907, continuous traffic of wireless telegraphy took place between the two countries (pp. 19–29).

Mercer (2006) explains that “radiophones” were bulky and weighty in the beginning, which restricted their usefulness. Still, they found their way for example to the armed forces (p. 107). Especially the “vacuum tube” allowed the production of bearable devices as used by the armed forces in the Second World War (Regal, 2005, p. 52).

According to Regal (2005), the Second World War was accompanied by a meaningful use of wireless telegraphy devices. It was used for propaganda by all sides but also on the battlefield. It was attached to u-boats, “tanks”, aircraft, and even carried by the infantry (p. 95).

**Meaningful events related to the development of wireless communication**

1. 1861: Reis develops the telephone (Mensch, 1975, p. 156).
2. 1872: Loomis patents his wireless device (Regal, 2005, p. 25).
3. 1876: Bell gets a patent for his telephone (Regal, 2005, p. 13).
4. 1895: Marconi can send and receive signals with his wireless device (Regal, 2005, p. 24).
5. 1899: Marconi reports on “America’s Cup” with his wireless device from a boat, making it “… the first confirmed public wireless transmissions in America” (Regal, 2005, p. 26).
   1899: “United States Navy” performs experiments with Marconi devices onboard two battleships (Regal, 2005, p. 44).

6. 1900: Fessenden is able to broadcast voice (Jewkes, Sawers & Stillerman, 1969, p. 286).
   About 1900: Use of the telephone by the military in campaigns (van Creveld, 1991, p. 174).
   1900: Marconi gets a patent for his work related to "tuning" (Regal, 2005, p. 28).
   After 1900–1902: "… first use of the wireless in warfare … during the Boar [sic!] War …" (Watson, 2009, p. 8).
7. December 1901: Marconi sends a signal from Great Britain to Canada, covering 2,100 miles (Regal, 2005, p. 28).
8. 1903: The "maneuvers" of the navy of the USA comprise the use of wireless communications (Winkler, 2010, p. 735).
9. 1905: Fessenden tries to get his "heterodyne system of detection" patented (Jewkes, Sawers & Stillerman, 1969, p. 287).
10. 1906: Military of the USA constructs a mobile wireless communications device (Winkler, 2010, p. 735).
    1906: Fessenden is able to transmit speech from Great Britain to the USA (Regal, 2005, p. 32).
    1906: Lee de Forest develops the "triode" (Jewkes, Sawers & Stillerman, 1969, p. 287).

**3.4.1.16.2. Full-scale application of wireless communication**

Fuller's (1998) evaluation of this innovation is that it "… introduced warlike possibilities which went far beyond anything as yet accomplished by either gunpowder or steam power" (p. 134). This is perhaps a bit overstated but in general wireless communication changed warfare meaningfully. According to Regal (2005), the navy of Great Britain was an early adaptor of "wireless telegraphy" and the navies of Germany and Italy followed suit soon, while the navy of the USA lagged behind somewhat. Already in 1906, the new technology was often used on ships in general and four years later, it was actually used on almost every ship (pp. 30, 44).

With regard to the First World War, the following applies to the armed forces of the USA: they initially used "flags" as well as "homing pigeons" for shorter distances and "submarine telegraph cables" for communication with the homeland (Winkler, 2010, p. 736). However, to some extent "radio" and "field telephones" were used as well (Winkler, 2010, p. 736). As devices for wireless transmission were still heavy and not suited for use in the field, the main devices used by the army of the USA during the

First World War were telephones and for longer distances telegraphs (Raines, 2011, pp. 185–186). The usual wartime boom is apparent in the personnel of the related units. The “Signal Corps” had 42 “officers” and 1,212 “enlisted men” in 1916 and 1,462 and 33,038 respectively at the end of the First World War (Terrett, 1956, pp. 20–21). According to Raines (2011) a meaningful device appeared in 1934. It was the “walkie-talkie”, which had a weight of about 12 kilograms and worked up to eight kilometers. It was portable by infantry soldiers and was improved over the coming years (p. 230).

Nevertheless, at the beginning of the Second World War, the armed forces of the USA were mostly equipped with out-dated wireless communications material (Winkler, 2010, p. 737). According to Raines (2011), equipment like telegraphs and telephones was used. Ever since 1943, an improved version of the “walkie-talkie” became available. Tanks and artillery were equipped with devices using FM, however problems regarding the communication between the different mentioned devices existed (p. 277). The advantage of “FM” is its increased effectiveness as well as efficiency for tactical wireless communication devices (Terrett, 1956, p. 183). A point regarding the German tanks in the Second World War has to be added: Van Creveld (1991) writes that the strength of the German tanks was mostly a result of their radio devices, which enabled them to send and receive, while the models of the Allies could not do so. Also the idea to link airplanes with forces on the ground by wireless communication was meaningful (pp. 180, 190).

Concerning the USA, by and large the equipment of the Second World War was used again during the Korean War (Raines, 2011, p. 325). During the Vietnam War however, the army of the USA equipped the soldiers in the field with improved radio communication devices (Raines, 2011, pp. 365–367). Especially the equipment of troops of the army with radio devices rose meaningfully from the Second World War to the Vietnam War (van Creveld, 1985, p. 238).

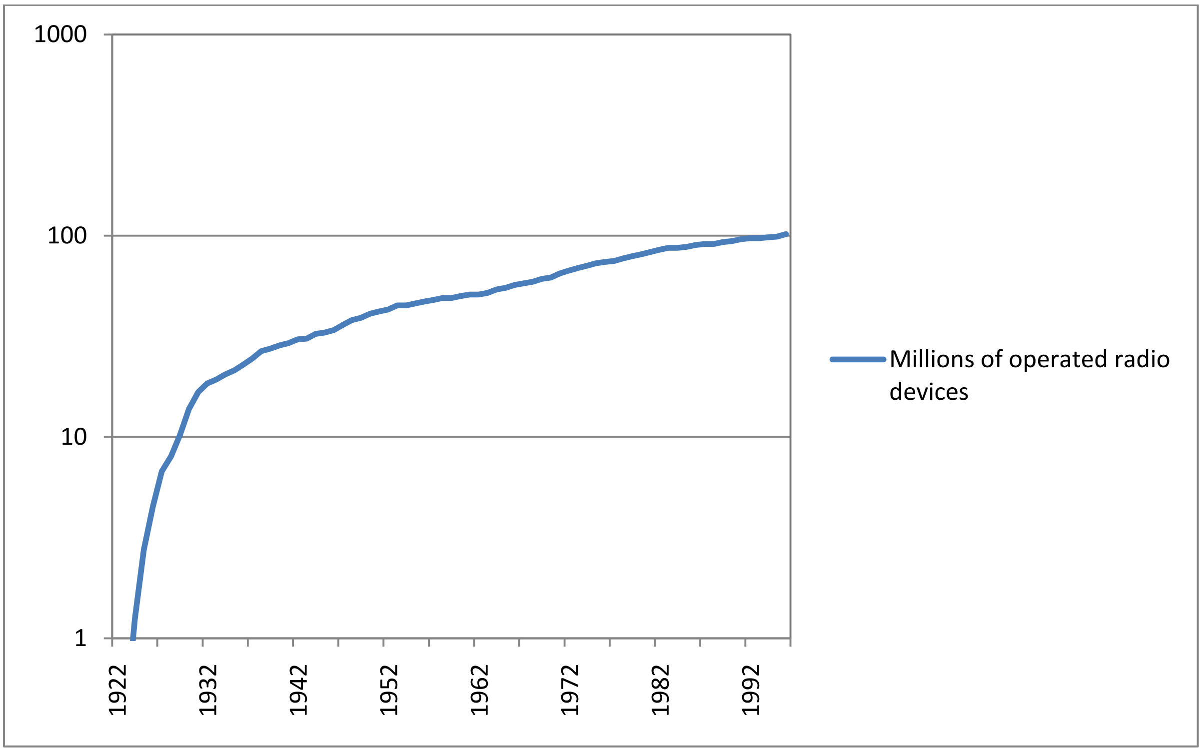


**Figure 14:** Millions of radio devices operated in the USA, 1922–1996.
(Own depiction, based upon Mitchell, 2003b, pp. 626–629)

Apart from the remarks regarding the full-scale application of wireless communication above, figure 14 provides data for showing the spreading of radio in the USA during the 20th century. It is suggested as a proxy for the groundbreaking innovation wireless communication.

### 3.4.1.16.3. Conclusion regarding wireless communication

The year 1899 is chosen for the groundbreaking innovation wireless communication. It is the year of Marconi's reports on "America's Cup". Even though wireless telegraphy came into full application quickly in the area of seafaring, it generally arose slowly only, as shown in figure 14. Therefore, it is categorized as a slow rise to full-scale application.

### 3.4.1.17. Airplane

Leonardo da Vinci suggested devices for flying already (Kinney, 2008, p. 2). Later on, scientists like Newton, Bernoulli and Euler made theoretical contributions to aviation in general (Brodie & Brodie, 1973, p. 173). In 1783, a person flew for the first time, utilizing "lighter-than-air balloons" (Kinney, 2008, p. 15). However, the history of aviation in the narrower sense starts around the year 1800 only.

### 3.4.1.17.1. Development of the airplane

According to Kinney (2008), Cayley was one of the most important pioneers in the field. In 1799, he made a drawing showing the sketch of an aircraft as well as theoretical contributions regarding aviation. Five years later, his small aircraft was the first one to look like the design that became predominant later on and fly successfully. Between 1809 and 1813, he wrote about his theoretical insights, which became an important source for people active in the field later on. In 1849 and 1853, he constructed a "glider" that flew with humans on board. It was the first time humans were able to fly with devices that were not lifted by the fact of being lighter than air (pp. 3–5). Further pioneers in the area were among others Henson, Pénaud and Maxim, the inventor of the Maxim machine gun (Kinney, 2008, pp. 5–6). Kinney (2008) writes that in 1890, the first steam-driven and manned aircraft flew. This device built by Ader was not suited for more sophisticated flight operations, though. In contrast, a similar design by Langley, which however had no passenger, was able to travel for about one kilometer in 1896 (pp. 6, 9).

Regarding manned flights with steerable aircraft, Brodie and Brodie (1973) write that the first short flight of the Wright brothers took place in December 1903. About a year later, they managed to perform a flight that lasted for more than half an hour. In 1909, Bleriot crossed the "English Channel" (pp. 175–176). The military use of the airplane came soon. The military of the USA got the first aircraft in 1908 (Huston, 2010, p. 444). Kinney (2008) writes that ever since 1911, it was used for warfare. The airplane has the following major roles on the battlefield: "bombing", "reconnaissance", "airlift" as well as fulfilling the task of a "fighter aircraft". When the First World War started, Germany possessed about 340 fighter airplanes, France 160 and Great Britain 80. Main task of airplanes was spotting enemy units. Nevertheless, the German "Fokker E fighter" was perhaps the first truly important aircraft used for war. An integrated device enabled firing through the rotating "propeller blades", which was a superior design at that time (pp. 22–25). Regarding the USA, Kinney (2008) mentions that they had some experience with airplanes by the start of the First World War. However, they only possessed 100 airplanes when they joined the war in 1917, which were all inappropriate for combat (pp. 33–34). When the First World War culminated, the Germans made 900 airplanes available for the offensive in early 1918, while the Allies were able to mobilize 2,000 half a year later (Brodie & Brodie, 1973, p. 179).

The years after the First World War came along with general improvements of airplanes, the increased civilian use of aircraft and for example the flight across the Atlantic by Lindbergh in 1927 (Kinney, 2008, pp. 45–55). At the time of the Second

World War, the airplane was fully established. The combination of wireless communication with airplanes was perhaps the most important improvement in comparison to the First World War (van Creveld, 1991, p. 190). The most notable development during the Second World War was the "Me 262" being "the world's first practical jet airplane", which was followed by the "Lockheed P-80 Shooting Star" being "the first practical American jet airplane" (Kinney, 2008, pp. 77, 82). The impact of jet airplanes during the Second World War was limited nevertheless. Later advances included the "Bell XS-1" traveling faster than the speed of sound in 1947 and a plane of the type "X-15" traveling at almost seven times the speed of sound and reaching an altitude of over 100 kilometers (Kinney, 2008, pp. 87–90). However, it became clear soon that increases in velocity are desirable until a certain limit only and airplane development focused on armament and electronic equipment instead (van Creveld, 1991, p. 276).

Kinney (2008) describes another important development: the rise of the "uninhabited aerial vehicle". Crude forms appeared during the Second World War but only during the following decades, they were used on a larger scale. Ever since they have developed rapidly and seem to have further potential for development (pp. 105–106, 141–142)

**Meaningful events related to the development of the airplane**

1. 1889: "Der Vogelflug als Grundlage der Fliegerkunst" by Lilienthal appears (Kinney, 2008, p. 7).
2. 1894: "Progress in Flying Machines" by Chanute appears, a work uniting the knowledge of its time regarding aviation (Kinney, 2008, p. 8).
3. 1896: Langley's aircraft propelled by steam flies for more than a kilometer (Brodie & Brodie, 1973, p. 175).
4. 17$^{th}$ December 1903: First flight of Wright brothers' aircraft (Huston, 2010, p. 444).
5. 1904: One of the Wright brothers flies for more than half an hour (Brodie & Brodie, 1973, p. 176).
6. 1906: Wright brothers patent their airplane (Kinney, 2008, p. 14).
7. 1915: German "Fokker E fighter", perhaps the first truly important aircraft used for war, appears (Kinney, 2008, p. 21).

### 3.4.1.17.2. Full-scale application of the airplane

Boot (2007) writes that the most important countries participating in the First World War had overall 774 airplanes in the beginning of the conflict. Overall output figures reached 200,000 at the end of it (pp. 207–208). However, Kinney (2008) evaluates the impact of the new weapon during the First World War as confined (p. 38).

Output figures concerning "combat aircraft" of the USA, Great Britain, the Soviet Union, Germany, as well as Japan for the period of the Second World War are in excess of 540,000 (Harrison, 2000, pp. 15–16). This reflects a massive quantitative change in comparison to the First World War. However, also the quality in the sense of speed, fighting power and so forth had changed as well. Meaningful missions carried out by airplanes during the Second World War stress the qualitative meaning they had reached at that time. Kinney (2008) mentions for example the "attack on Pearl Harbor" in late 1941, the "Normandy invasion" in 1944, and the delivery of the two nuclear weapons in 1945 (pp. 63–64, 70, 75). Fuller (1998) adds that the Allied thrust into Germany was supplied with half a million gallons of gas per day by airplanes, making the thrust possible only (p. 153). Further meaningful events included according to Kinney (2008) the Berlin Blockade and the role of airplanes in the "SAC" after the Second World War (p. 92).

The meaning of the airplane in the civilian sector and thereby to some extent also the general meaning is reflected by figures 15 and 16, showing important measures related to aviation for the USA as well as Great Britain.

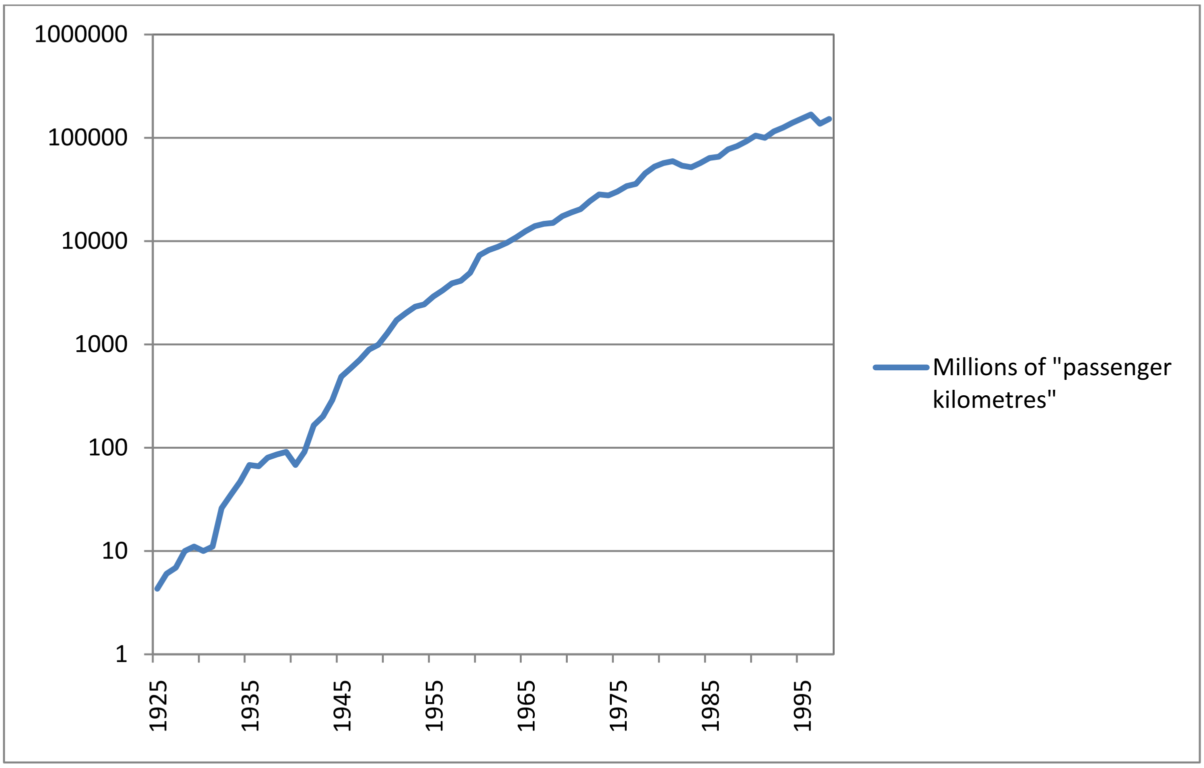


**Figure 15:** Millions of “passenger kilometres” in Great Britain, 1925–1998.
(Own depiction, based upon Mitchell, 2003a, pp. 745–748)

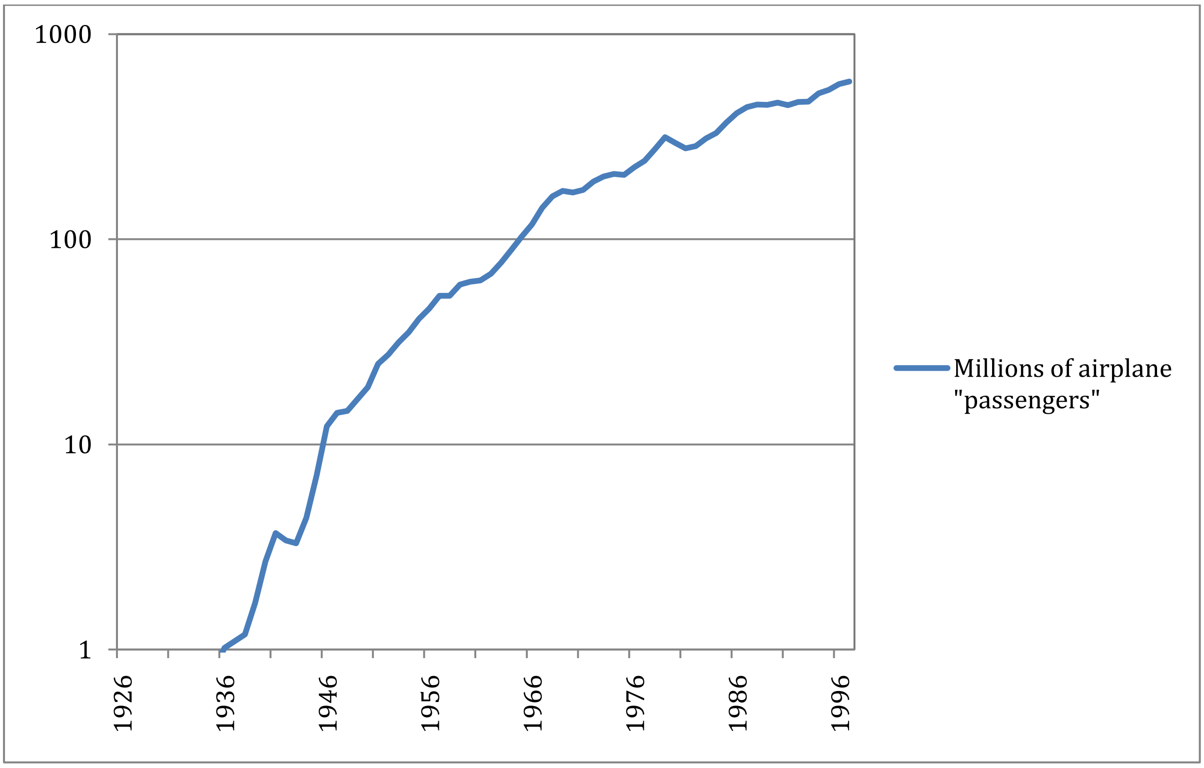


**Figure 16:** Millions of airplane “passengers” in the USA, 1926–1997.
(Own depiction, based upon Mitchell, 2003b, pp. 600–604)

### 3.4.1.17.3. Conclusion regarding the airplane

The airplane emerged during the 19th century, which witnessed many models and designs that were successful to a varying degree. Only the Wright brothers constructed a workable model, which they were able to fly for an extended period of time soon. Therefore, the year of the first successful flight by the Wright brothers in 1903 is chosen as the year of the groundbreaking innovation airplane. As the opportunities offered by the airplane to the military were obvious (van Creveld, 1991, p. 185), the further development started quickly with the first use during an armed conflict just eight years after the flight by the Wright brothers. Overall, it is an innovation that reached full application slowly only, as the role during the First World War was still limited. The data related to civilian aviation display a similar picture.

### 3.4.1.18. Gas

Already almost 2,500 years ago, gas was used in Ancient Greece during "the siege of Delium" (Brodie & Brodie, 1973, p. 15). Later, the idea to employ it in warfare was suggested by Leo VI, which dates back more than 1,000 years and it reappeared at times ever since (Hogg, 1970, p. 178). Overall, in this dissertation, the word gas is used to describe all chemical weapons used during the First World War. As Hogg (1975) explains, were neither all used chemical weapons "gases", nor all "gases" "gaseous" (p. 12). Before going more into detail, it has to be mentioned that in 1899 at the "first Hague Conference" it was decided to ban "projectiles" "'for the diffusion of asphyxiating or deleterious gases'" (Hogg, 1975, p. 23). Furthermore, the focus is directed on the use of gas and not on the different gases, their discovery and production, which would be accompanied by getting lost in detail. However, most gases were discovered decades before the First World War. For example, the respective year for "mustard gas" is 1886 (Väyrynen, 1978, p. 178).

### 3.4.1.18.1. Development of gas

Hogg (1975) explains that the French police used "tear gas" in 1912 and that thereafter, the armed forces of France adopted a "rifle grenade" containing "ethylbromoacetate", which might have been used early during the First World War (pp. 18–19). Hogg (1975) explains that after the failure of using artillery grenades filled with "xylyl bromide" in early 1915, the German military decided to use "chlorine" released from containers, which took place on 22nd April 1915. The impact of the "168 tons of chlorine" was larger than anticipated, which meant that it could not be utilized to the full extent (pp. 23–28). As the war went on, using gas became

common (Hogg, 1975). About 3,000 substances were examined for application and finally 38 were also employed (Hogg, 1975, p. 17).
Haber (1986) mentions that in 1925, the "Geneva Protocol" was created that also dealt with banning "chemical and bacteriological weapons". Many countries promised to stay away from using them; however, for example the United States of America did not "ratify" it (pp. 295–296).

**Meaningful events related to the use of gas**

1. 1912: "Tear gas" used in France (Hogg, 1975, p. 18).
2. 1914: Use of "rifle grenades" filled with "ethylbromoacetate" (Hogg, 1975, pp. 18–19).
   1914: Germany develops the "'T-Shell'", containing "7lbs of xylyl bromide", it does not work as intended (Hogg, 1975, p. 23).
3. 1915: Haber suggests to simply release "chlorine" from containers, which was done on 22nd April 1915 (Hogg, 1975, pp. 24–25).
   2nd May 1915: A similar attack takes place in the East, the result is that the "Bolimov position" is overcome (Hogg, 1975, p. 32).
   25th September 1915: Armed forces of Great Britain release 140,000 kilograms of "chlorine" at Loos (Haber, 1986, pp. 55–56).
4. 1916: Great Britain tests the "'Livens Projector'", a device for delivering gas containers (Hogg, 1975, p. 50).
   1916: France and Germany use artillery grenades filled with "phosgene" and "diphosgene", respectively (Haber, 1986, pp. 94–95).
5. 9th April 1917: 3,827 "Livens Projectors" used, delivering 51,000 kilograms of "phosgene" (Hogg, 1975, pp. 55–56).
   1917: "Mustard gas" adopted by Germany (Brodie & Brodie, 1973, p. 194).
   Late 1917: "cloud gas" inefficient as enemy soldiers know well how to react properly (Hogg, 1975, pp. 109, 113).
6. 1918: "'Beam system'" adopted by Great Britain, it works better than "cloud gas" (Hogg, 1975, pp. 104, 109).
   1918: "Mustard gas" employed by Great Britain and France (Hogg, 1975, p. 127).
7. 1925: Use of gas banned by the "Geneva convention" (O'Connell, 1989, p. 254).

### 3.4.1.18.2. Full-scale application of gas

Gas was used on a large scale during the First World War only. Regarding produced quantities of the main gases, Haber (1986) provides an overview (p. 170). However, the numbers per se are not very informative. The main belligerents produced for example 93,800,000 tons of chlorine and 11,000,000 tons of mustard gas (Haber, 1986, p. 170). Casualty data might provide a better gauge. For the impact on soldiers of the USA, the following applies according to Brodie and Brodie (1973): the overall number of injured soldiers was 258,000 and about 64,500 of them were injured by gas. The deadliness of it was much lower than the one of other arms, however. It was 2% compared to 25% of the injured (p. 195). Fuller (1998) provides slightly diverging numbers (p. 159), which nevertheless confirm the general picture. However, the extent of personal suffering of the injured soldiers stays beyond the scope of the displayed numbers. Looking at the overall injured of the war, 5% or 1,286,853 were injured or lost their life by "gas" (Hogg, 1975, p. 136). The fact that gas accounts for 25% of casualties of the soldiers of the USA during the First World War highlights the meaning of the use of gas. Furthermore, it generated frictions towards the units affected by it, for example by forcing them to use a gas mask (Hogg, 1975, p. 60).

### 3.4.1.18.3. Conclusion regarding gas

The date for the groundbreaking innovation gas is 1915. Even though the police presumably used it in 1912 already and the early applications in grenades by France and Germany in the First World War predate 1915, the mentioned cases did not work as intended. Only in 1915, it was used effectively. As the use of gas was banned in 1925, a full-scale application comparable to the other groundbreaking innovations did not take place. The German lead in the utilization of gas in the First World War came from her strong position in the area of chemistry (Hogg, 1975, p. 89). It is a close relationship to the technological reality of the third Kondratieff cycle.

### 3.4.1.19. Tank

The "chariot (own translation)" can be seen as an early predecessor of the tank (Macksey & Batchelor, 1978, p. 5). Apart from ideas by Leonardo da Vinci and others, Zizka's use of specially designed wagons mostly used for static operations early in the 15$^{th}$ century is noteworthy (Macksey & Batchelor, 1978, pp. 6–7).

### 3.4.1.19.1. Development of the tank

The tank can be seen as an attempt to overcome the stalemate during the First World War (Ellis, 1986, pp. 167–168). Macksey and Batchelor (1978) write that the "internal-combustion engine (own translation)" was essential for the rise of the modern tank. An early crude design of an armed engine-powered vehicle appeared in 1899 and was designed by Simms. Models with similarities to armored reconnaissance cars followed since 1906 and in 1912, Italy used one by Bianchi during an armed conflict (pp. 9–10). However, it did not use chains. This is also the reason why the early models were unsuited for combat in the battlefields of the First World War (Macksey & Batchelor, 1978, p. 13). Nevertheless, "armored reconnaissance cars (own translation)" played an important role in the Second World War (Macksey & Batchelor, 1978, pp. 90–91). The problem of developing suitable "caterpillar tracks (own translation)" was finally solved late in 1915 and the "'Mother'" type was ready in January 1916, which was very similar to the model "Mark I" (Macksey & Batchelor, 1978, pp. 23–25).

Weller (1966) mentions 15th September 1916 as the day of the first appearance of the new weapon in battle (p. 91). However, Macksey and Batchelor (1978) explain that in the beginning, they were used ineffectively. Only after tactics were changed and the new concept was tried near Cambrai in 1917 using 376 of them, a major success was the consequence (pp. 28–29). Their meaning during the First World War was nevertheless limited (Ford, 1997, p. 12). Meaningful were Fuller's suggestions expressed in the 1918 "'Plan 1919'", which sketched the most efficient use of the new weapon (Macksey & Batchelor, 1978, p. 48).

**Meaningful events related to the development of the tank**

1. 1899: Simms develops an armed and engine-driven model with four wheels (Macksey & Batchelor, 1978, p. 9).
2. 1912: Italy uses a model by Bianchi during an armed conflict (Macksey & Batchelor, 1978, p. 10). It did not use chains, however.
   1912: De Mole suggests a crude tank to the army of Great Britain (Ford, 1997, p. 7).
3. 1915: Davidson performs a maneuver in the USA with the participation of a "fully armored car (own translation)" (Macksey & Batchelor, 1978, p. 17).

4. 16th January 1916: "'Mother'" type was ready (Macksey & Batchelor, 1978, p. 24).
15th September 1916: First appearance of a "tank" in battle (Weller, 1966, p. 91).
5. 1918: Fuller writes the "'Plan 1919'", sketching the most efficient use of the new weapon (Macksey & Batchelor, 1978, p. 48).
6. 1924: "'Light Tank Mk I'" is the earliest model of Great Britain that features a "swiveling turret (own translation)" (Ford, 1997, p. 21).
7. Since 1934: "Welding (own translation)" used for the construction of "tanks (own translation)" in Germany, Great Britain does so later only (Macksey & Batchelor, 1978, p. 100).

#### 3.4.1.19.2. Full-scale application of the tank

The most important qualitative change the tank brought was that it could be used to break the power of the defense and bring mobility back to the battlefield. Table 3 provides an overview regarding output figures of tanks of the Mark types in Great Britain during the First World War. The overall production figures concerning tanks in Great Britain during the First World War might be about 3,000 (Brodie & Brodie, 1973, p. 199).

**Table 3:** Output figures concerning tanks of the model "Mark" of Great Britain during the First World War. (Own depiction, based upon Foley, 2014, pp. 42, 46, 50, 51)

| Model | Output figures |
|---|---|
| Mark II | 50 |
| Mark III | 50 |
| Mark IV | >1,000 |
| Mark V | 400 |
| Mark VII | 3 |
| Mark VIII | 24 (in Great Britain) |

Regarding the situation in the USA, the following applies: Foley (2014) writes that the construction of the new weapon did not start early enough to provide meaningful numbers for use in France. The forces of the USA mostly used French models instead (pp. 62–63).

Tanks were developed further over the following decades regarding armour, weapons and engines. Also wireless communications were essential for an effective use of the new weapon (Ford, 1997, p. 39). However, the concept of the tank did not change. Especially the early phase of the Second World War witnessed cases where the tank was used with maximum effectiveness. "… the largest tank battle of the Second World War – probably even of all times … (own translation)" took place in 1943 at Kursk where about 6,000 of them participated (Ford, 1997, p. 51). The overall output figures for "tanks" and "self-propelled guns" for the USA, Great Britain, the Soviet Union, Germany, as well as Japan for the period of the Second World War are in excess of 280,000 (Harrison, 2000, pp. 15–16). The meaning the tank gained during the Second World War did not diminish in the decades afterwards (Ford, 1997, p. 43).

**3.4.1.19.3. Conclusion regarding the tank**

The year 1916 is the year the groundbreaking innovation tank appeared. The model Mother by Great Britain appeared in 1916 and also did the first use of tanks in battle occur in the same year. The Italian armored reconnaissance car used during combat in 1912 did not feature chains, which are an essential characteristic of battle tanks enabling mobility in difficult terrain. The spread to full-scale application is rather a case of relatively slow dissemination. During the First World War, they were often used in a tactically unfavorable manner and only during the Second World War their proper use became common.

**3.4.1.20. Radar**

"*ra*dio *d*etection *a*nd *r*anging" (Reintjes & Coate, 1952, p. 1) is where this innovation derives its name from. It can be defined as follows:

> Radar is a system of radiolocation which employs short-wave radio waves to detect objects. The waves are sent out in pulses, strike the objects, are reflected back to the receiving set and from the data gathered there, the position of the object is accurately determined. (Jewkes, Sawers & Stillerman, 1969, p. 283)

According to Reintjes and Coate (1952), it has meaningful qualities like its independence of the "weather" and its general long reach. Naval use of it helps avoiding accidents; the same is true in the field of aviation. During the Second World War, it helped to steer naval vessels and aircraft as well as guiding bombing and artillery fire. Furthermore, it was used to detect enemy naval vessels and airplanes (p. 1).

Farina (2008) adds that using it comes with the possibility of “electronic countermeasures” as well as ”electronic counter-countermeasures”. “Electronic countermeasures” include for example “jamming” or the use of “decoys”, while “electronic counter-countermeasures” try to deal with the former (pp. 24.1, 24.5).

### 3.4.1.20.1. Development of radar

Faraday, Hertz, and Maxwell all provided important theoretical knowledge to the field (Watson, 2009, p. 3). Hertz showed in 1886 that certain objects could return “electromagnetic waves” (Watson, 2009, p. 29). In 1904, Hülsmeyer patented his crude radar device (Watson, 2009, p. 29). During the summer of 1935, “radar” worked for the first time in Great Britain (Watson, 2009, p. 50). Also a naval vessel from France was equipped with some kind of radar device in 1935 (Buderi, 1997, pp. 63–64). First tests with radar on an airplane were performed in Great Britain in 1936 (Watson, 2009, p. 63). In 1938, the first ships of the naval forces of Great Britain were equipped with radar (Watson, 2009, pp. 74–75). According to Brodie and Brodie (1973), Great Britain had developed the “multicavity magnetron” by 1940 that increased the power of radar meaningfully by enabling the use of waves with a length down to 10 cm instead of the 150 cm used earlier. Two years later, even the use of 3 cm waves became possible, providing even better results (pp. 208–209). Around about the same time, similar developments took place in the USA (Terrett, 1956, p. 121), Italy (Galati, 2016, pp. 30–46), Germany (Galati, 2016, pp. 69–71) and Japan (Galati, 2016, pp. 76–77).

**Meaningful events related to the development of radar**

1. 1900: Tesla mentions that what today is performed by radar is possible (Terrett, 1956, p. 41).
2. 1904: Hülsmeyer patents a crude device, making him “the undisputed inventor of radar” (Galati, 2016, p. 1).
3. 1922: Marconi describes some kind of modern radar (Jewkes, Sawers & Stillerman, 1969, p. 283).
4. 1925: Tuve and Breit “… measured the height of the layers of the ionosphere …” by using “radar” (Galati, 2016, p. 58).
5. 1930: Finding in the USA that airplanes reflect radio waves (Jewkes, Sawers & Stillerman, 1969, p. 285).

6. June 1935: Radar device in Great Britain is able to spot aircraft (Terrett, 1956, p. 42).
   Late 1935: "… five radar stations on the east coast of England comprised the first operational radar system in the world" (Brodie & Brodie, 1973, p. 208).
   1935: "First peaceful application … in France", a ship was equipped with a radar device (Jewkes, Sawers & Stillerman, 1969, p. 283).
   1935: Watson-Watt patents his design (Galati, 2016, p. 87).
7. 1936: First tests with radar on an airplane are performed in Great Britain (Watson, 2009, p. 63).
8. 1938: Armed forces of the USA equip first ships with "radar" equipment (Jewkes, Sawers & Stillerman, 1969, p. 285). So does Great Britain (Watson, 2009, p. 75).
9. 1939: "… Germany, Great Britain, Holland and the USA all possessed military radar apparatus …" (Jewkes, Sawers & Stillerman, 1969, p. 283).
10. Late 1930s: Aircraft are equipped with "radar" in Great Britain (Galati, 2016, pp. 149–150).
11. 1940: Great Britain develops the "multi-cavity magnetron", which amplifies the power of radar (Brodie & Brodie, 1973, pp. 208–209).
    1940: Anglo-American collaboration regarding their "radar" research (Jewkes, Sawers & Stillerman, 1969, p. 285).
12. 1942/1943: "Centimetre-wave radar" increases power of "radar" devices (Jewkes, Sawers & Stillerman, 1969, p. 285).

### 3.4.1.20.2. Full-scale application of radar

O'Connell (1989) writes that in December of 1935, five radar installations protected the British East coast. In 1940, a total of "twenty-one long-range stations and an additional thirty low-level installations" were in order. They had a meaningful impact on the outcome of the Battle of Britain (p. 278). They enabled identifying incoming German airplanes in time as well as planning and directing the deployment of interceptors (Kinney, 2008, p. 60). Managing the gathered data and deciding correctly based upon it was equally important as spotting enemy airplanes (van Creveld, 1991, p. 192).

Important to mention is also the jamming of radar and countermeasures against radar. Brodie and Brodie (1973) argue that jamming enemy radar and finding solutions for the enemy jamming the own radar took place during the Battle for Britain already (pp. 210–211). Also the Channel Dash was accompanied by major "jamming" (Buderi, 1997, p. 205). Brodie and Brodie (1973) write that only the jamming of German radar enabled further bomber raids in Germany after 1943 as German anti-aircraft fire directed by radar inflicted heavy losses on Allied bombers (p. 212). The use of "'chaff'" amounted to more than 4,500 tons for a part of the air force of the USA alone during the Second World War in Europe (Brodie & Brodie, 1973, p. 211). It was designed in Great Britain and Germany after 1940 (Galati, 2016, p. 109). An example of a countermeasure during the Second World War is "Naxos" a device that enabled German u-boats on the surface to notice that they were spotted by enemy radar and provided thereby the opportunity to dive timely (van Creveld, 1991, p. 271). "*Metox*" preceded it, which entered service in mid 1942 (Buderi, 1997, p. 155).

Of course, radar is used for military applications until today. However, especially the control of aircraft in general became an important field of use after the Second World War (Galati, 2016, p. 131). Skolnik (2008) adds another field of application, which arose with the advent of "ballistic missiles". Detecting them is complicated for many reasons like the extreme velocity or the relatively little appearance, amongst others (p. 1.21). This problem became apparent after 1950 (Buderi, 1997, p. 405). The surveillance of the "weather" is another field that gained importance since the 1950s and plays an important role today (Keeler & Serafin, 2008, p. 19.1). However, further fields of use include "ground penetrating radar" to search for items in the soil (Daniels, 2008, p. 21.1) or "civil marine radar", with approximatively 3,000,000 ships using such a device making it "… the largest radar market of all time" (Norris, 2008, p. 22.1).

#### 3.4.1.20.3. Conclusion regarding radar

The year 1935 is chosen for the appearance of this groundbreaking innovation in weapons technology. It is the year of the first use on a naval vessel as well as for surveillance of the airspace of Great Britain. It seems acceptable to argue that it had reached its full meaning quickly, making it rather a paradigm change than a slow rise to full-scale application.

### 3.4.1.21. Ballistic missile

According to Carman (1955), the use of rockets for military purposes is documented for the 14th century, not only in China but in Europe as well. More recent actions include Congreve's rockets, which were used during an assault on Boulogne in 1806. In general, rockets were used during the Napoleonic Wars, the Crimean War, and also smaller conflicts taking place in the colonies (pp. 189–196). The ballistic missile appeared during the Second World War (van Creveld, 2008, p. 175). It can be defined as follows:

> The rocket is a *ballistic* missile which, after its engine has stopped functioning, either because its fuel supply is burned up or because it is shut off, continues on its path through space entirely on its own momentum, following a trajectory which, like that of any freely flying object, tends to be parabolic … The ballistic missile, … , carries not only its fuel but also a supply of oxygen for burning that fuel, … (Brodie & Brodie, 1973, p. 226)

A ballistic missile can be directed either wireless from somewhere else or through devices inside that have been preset earlier to launching (Brodie & Brodie, 1973, p. 227).

#### 3.4.1.21.1. Development of the ballistic missile

An early contributor to the field was Ziolkovsky. Van Riper (2007) writes that he made theoretical contributions during the last decades of the 19th century. He understood for example that the prevailing design of missiles was not sufficient to enable more powerful devices. He suggested among other things "multistage rockets" and the use of "liquefied oxygen" to enable the device to travel through airless space. Two later figures are Goddard and Oberth who further contributed to the field with publications but especially Goddard also practical developments like "the first flight of a liquid-propellant rocket" (pp. 27–34). Van Riper (2007) opines that also the German, American, and Soviet "rocket societies", where people constructed crude devices mostly in the 1930s were important concerning the development of rockets. Soon, the armed forces of the mentioned countries became interested in their work and different forms of cooperation ensued (pp. 34–40).

Van Riper (2007) explains that the German "V-2" was the "world's first operational ballistic missile". It had "a single-chamber rocket motor" and was directed by a device inside it, the accuracy was not very high, nevertheless (p. 54). It was powered by "alcohol" and "hydrogen peroxide" and in fact, there was no possibility of defense against it (Brodie & Brodie, 1973, pp. 231–232). The first successful flight took place on 3rd October 1942 (Reichl, 2016, p. 7). Van Riper (2007) explains that after the Second World War, the USA as well as the Soviet Union developed them further; the development peaking with the Soviet "R-5M" and the "Redstone" of the USA, both were able to carry an atomic bomb. Improvements regarding the rocket motor, directing the rockets, as well as detaching the payload from the rocket took place. The resulting "IRBMs" had ranges up to ten times what the V-2 had. "ICBMs" as well as "SLBMs" emerged soon. The first "ICBM" overall was the Soviet "R-7" that could travel up to 3,000 miles. It appeared in 1957. After 1960, "ICBMs" were stored in "'silos'" to protect them and ensure a quicker launching process. The advantage of "SLBMs" is, especially in combination with the highly independent "nuclear-powered submarine" that the position of the submarine and its rockets is unknown and therefore a rocket launch by the submarine cannot be prevented. Therefore, they played a meaningful role concerning "MAD" (pp. 72–80). The idea to deliver nuclear weapons with rockets arose after the USA dropped the first one on Japan already (Neufeld, 1990, p. 59). A related development concerns the number of warheads one missile carries: Brodie and Brodie (1973) explain the meaning of using many warheads in one rocket. It makes it even more difficult to defend a target and also is it possible to add "decoys", which further complicate the task. Being able to direct the single warheads leads to an even higher degree of complication, especially as an earlier split of the single parts enables finally a larger target area. This system is called "MIRV" (pp. 295–296).

**Meaningful events related to the development of the ballistic missile**

1. 1903: Ziolkovsky writes on theoretical fundaments of "space travel" (Jewkes, Sawers & Stillerman, 1969, p. 289).
2. 1923: "*The rocket into Interplanetary Space*" by Oberth appears, which contains fundamental knowledge concerning the topic and influenced pioneers in the area (Jewkes, Sawers & Stillerman, 1969, pp. 289–290).
3. 1926: "… Goddard fired the world's first liquid-fueled rocket …" (Neufeld, 1990, p. 35).
4. 1933: "A1" constructed (Hogg, 1970, p. 256).
5. 1934: "A2" constructed, which could reach "… a height of 6,500 feet" (Hogg, 1970, p. 256).
6. 1938: "A3" constructed, "it was 25 feet long and 2 ½ feet in diameter, weighed 1,650 lb., had a ground range of 11 miles and reached an altitude of 40,000 feet" (Hogg, 1970, p. 256).

7. 1942: The “V2” rocket “… covered a distance of 120 miles with a deflection of only 2½ miles from the target, reached a speed of over 3000 m.p.h. and a height of nearly 60 miles” (Jewkes, Sawers & Stillerman, 1969, p. 291).
8. 1957: “The Soviet Union’s first ICBM, the R-7, flew for the first time …” (van Riper, 2007, p. 75).
9. 1960: “First missile-carrying submarines become operational” (van Riper, 2007, p. XII).
10. 1961: “First successful launch of a silo-based missile” (van Riper, 2007, p. XII).

**3.4.1.21.2. Full-scale application of the ballistic missile**

The main actors of the Cold War were the USA and the Soviet Union and the tensions became apparent during the last stages of the Second World War already. Therefore, looking at both countries is adequate. “Ballistic missiles” spread ever since the end of the Second World War, as the first Soviet model “R-1” appeared in 1948 and the first model of the USA “Redstone” in 1953 (van Riper, 2007, p. 72). Also in general, ballistic missiles were widely distributed during the Cold War (van Riper, 2007, pp. 147–150). To avoid getting lost in detail, it seems adequate to focus on production data for ICBMs for the USA and the Soviet Union, as they are the ultimate form of delivering nuclear weapons over long distances and were extremely meaningful during the Cold War.

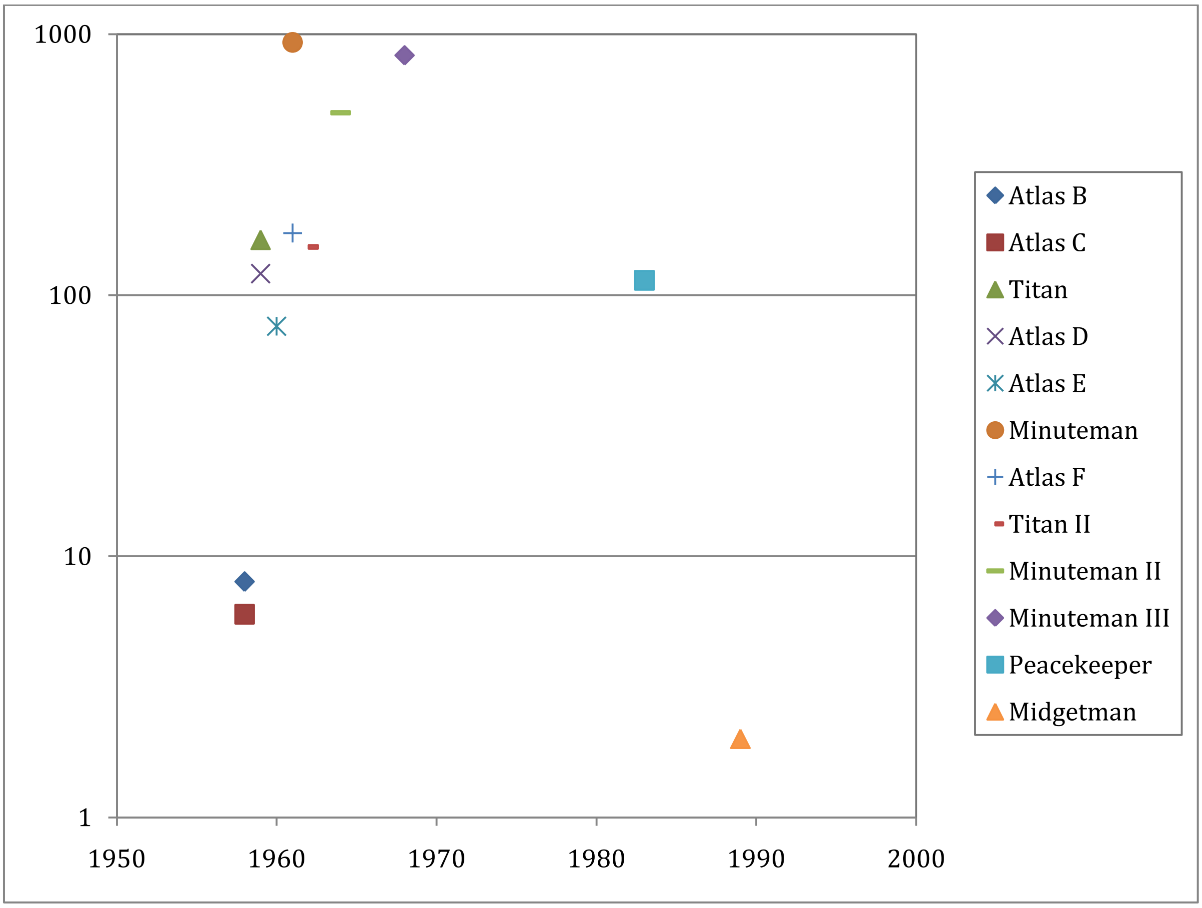


**Figure 17:** ICBMs of the USA, their years of first flight and approximate overall output figures. (Own depiction, based upon Reichl, 2016, pp. 136–143)

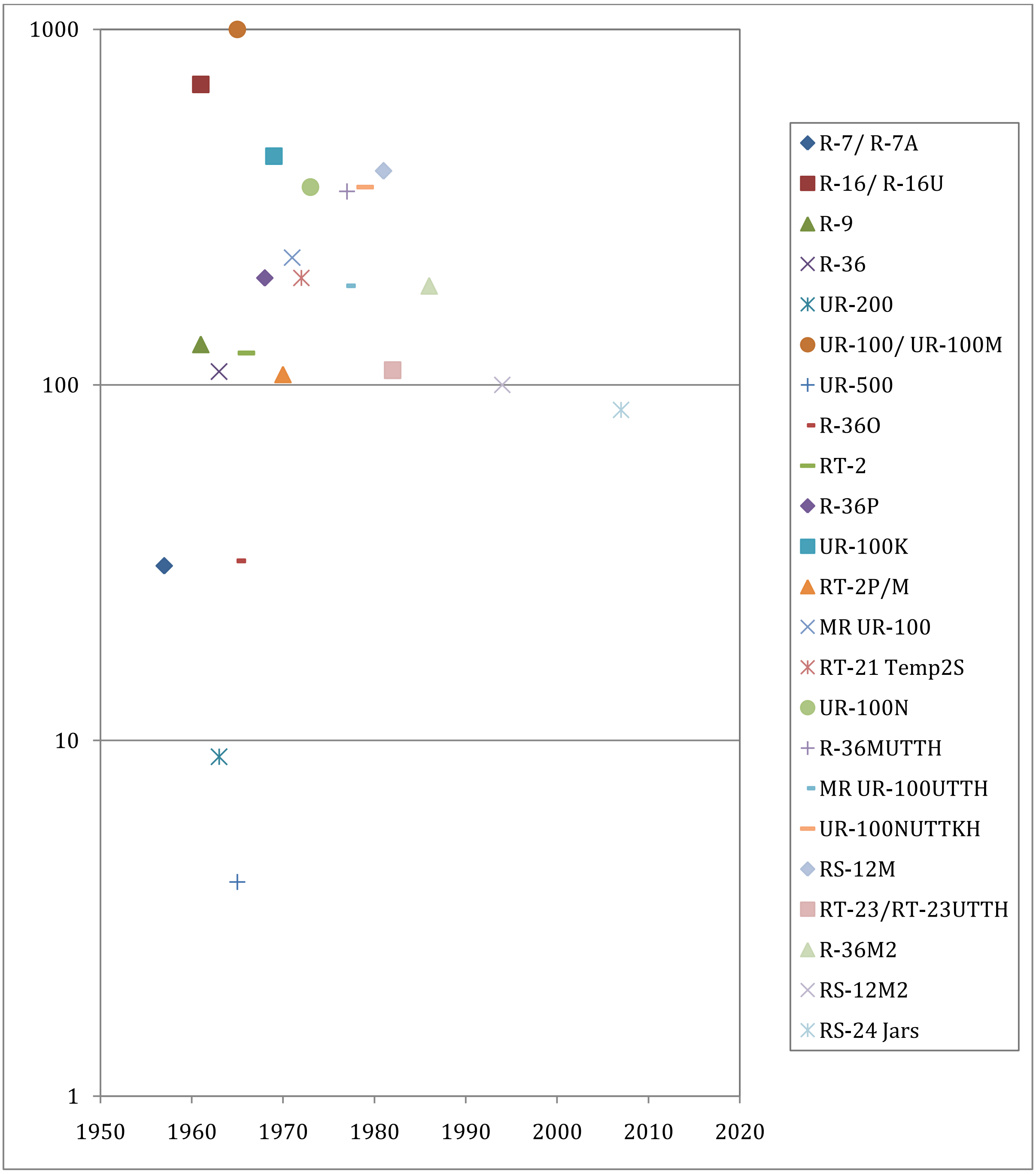


**Figure 18:** ICBMs of the Soviet Union, their years of first flight and approximate overall output figures. (Own depiction, based upon Reichl, 2016, pp. 136–143)

### 3.4.1.21.3. Conclusion regarding the ballistic missile

The year 1942 is chosen for the groundbreaking innovation ballistic missile, as it was the year of the first flight of such a device. With the first Soviet design appearing in 1948 and the first one of the USA in 1953, a relatively quick application by other countries than Germany after six and eleven years took place. Especially the ICBM models of the 1960s were produced on a large scale but particularly the Soviet Union produced ICBMs relatively steadily ever since with new missiles in every decade.

Therefore, it seems fair to categorize the ballistic missile as a slow rise to full application. Van Creveld (1991) writes that the new weapon was an innovation finding its way to the materiel of the army, even though it was unrelated to it in the beginning (p. 221). It found its way back, however. A Soviet “R-7 ICBM” was used to put “*Sputnik I*” into space and also in general, the related technology made possible using “satellites” with all the related civilian applications (van Riper, 2007, pp. 81, 84).

**3.4.1.22. Nuclear weapons**

Nuclear weapons are to some extent different relative to the other groundbreaking innovations, as most of them were described centuries earlier already or crude devices available for a long time. Apparently, this is not the case for nuclear weapons.

**3.4.1.22.1. Development of nuclear weapons**

Nuclear weapons are complex devices and the development can only be sketched here. Important for their development were advances in chemistry as well as physics. Important was Becquerel’s finding of “radioactivity” in 1896 (Brodie & Brodie, 1973, pp. 233–234). Later on, important theoretical contributions followed. For example, Einstein’s “relativity theory” was published in 1905 (Brodie & Brodie, 1973, p. 234). Chadwick found “the neutron (own translation)” in 1932 (Jungk, 1982, p. 52) and six years later Strassmann as well as Hahn were able to induce a “‘nuclear fission’” of “uranium” (Powaski, 1987, p. 3).

The development of nuclear weapons in the narrower sense began with the start of the Manhattan project. It was started on 13th August 1942 (Powaski, 1987, p. 6). In the same year, a team of researchers including Fermi started “the first nuclear chain reaction” (Powaski, 1987, p. 6). The manufacture of “uranium-235” and “plutonium” took place at other sites, while at Los Alamos, the nuclear device was built (Powaski, 1987, p. 6). “The first atomic bomb” exploded on 16th July 1945 (Powaski, 1987, p. 22) and the first “hydrogen bomb” followed on 1st November 1952 (Powaski, 1987, p. 59).

**Meaningful events related to the development of nuclear weapons**

1. 1927: Atkinson and Houtermans publish on “fusion” (Brodie & Brodie, 1973, p. 235).
2. 1932: Chadwick finds “the neutron (own translation)” (Jungk, 1932, p. 52).
3. 1934: Fermi and colleagues find the “‘moderator’” (Brodie & Brodie, 1973, p. 237).

4. 1938: Strassmann as well as Hahn are able to induce a "'nuclear fission'" of "uranium" (Powaski, 1987, p. 3).
5. 1939: The USA start the "Uranium Committee", which deals with questions related to nuclear weapons (Powaski, 1987, p. 5).
6. Mid 1942: Teller describes the possibility of a weapon based upon "'fusion'" (Jungk, 1942, p. 245).
   13th August 1942: "Manhattan Project" started (Powaski, 1987, p. 6).
   2nd December 1942: "… the first nuclear chain reaction" is started (Powaski, 1987, p. 6).
7. 16th July 1945: Explosion of "the first atomic bomb" (Powaski, 1987, p. 22).
8. 1946–1947: Tuck and Ulam write on topics related to the hydrogen bomb (Jungk, 1982, p. 254).
9. 3rd September 1949: Explosion of a Soviet nuclear weapon becomes known (O'Connell, 1989, p. 303).
10. 31st January 1950: USA decide to complete the "hydrogen bomb (own translation)" (Jungk, 1982, pp. 262–263).
11. 1st November 1952: First "hydrogen bomb" detonated (Powaski, 1987, p. 59).
12. 12th August 1953: Presumably first test of a hydrogen bomb by the Soviet Union (Jungk, 1982, pp. 282–283).

#### 3.4.1.22.2. Full-scale application of nuclear weapons

The only uses of nuclear weapons during a conflict so far took place in 1945. Kinney (2008) writes that on 6th August 1945, the raid on Hiroshima inflicted 120,000 casualties and destroyed 80 % of Hiroshima. The raid on Nagasaki on 9th August 1945 inflicted 75,000 casualties. A further consequence might have been the capitulation of Japan and the end of the Second World War (p. 75). However, nuclear weapons spread in the decades after the Second World War. The following figures provide an overview regarding the USA as well as Great Britain. Furthermore, it is noteworthy that they also found their way into tactical devices (Boot, 2007, p. 307).

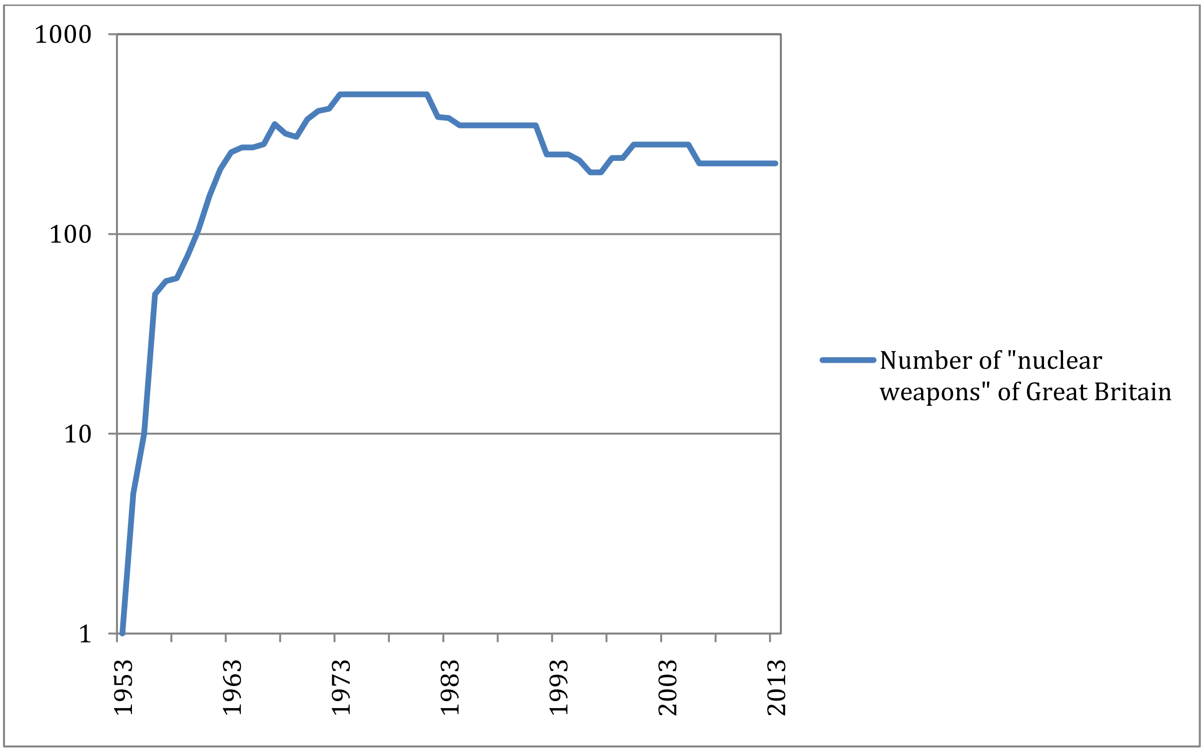


**Figure 19:** Number of “nuclear weapons” of Great Britain.
(Own depiction, based upon Kristensen & Norris, 2013, p. 78)

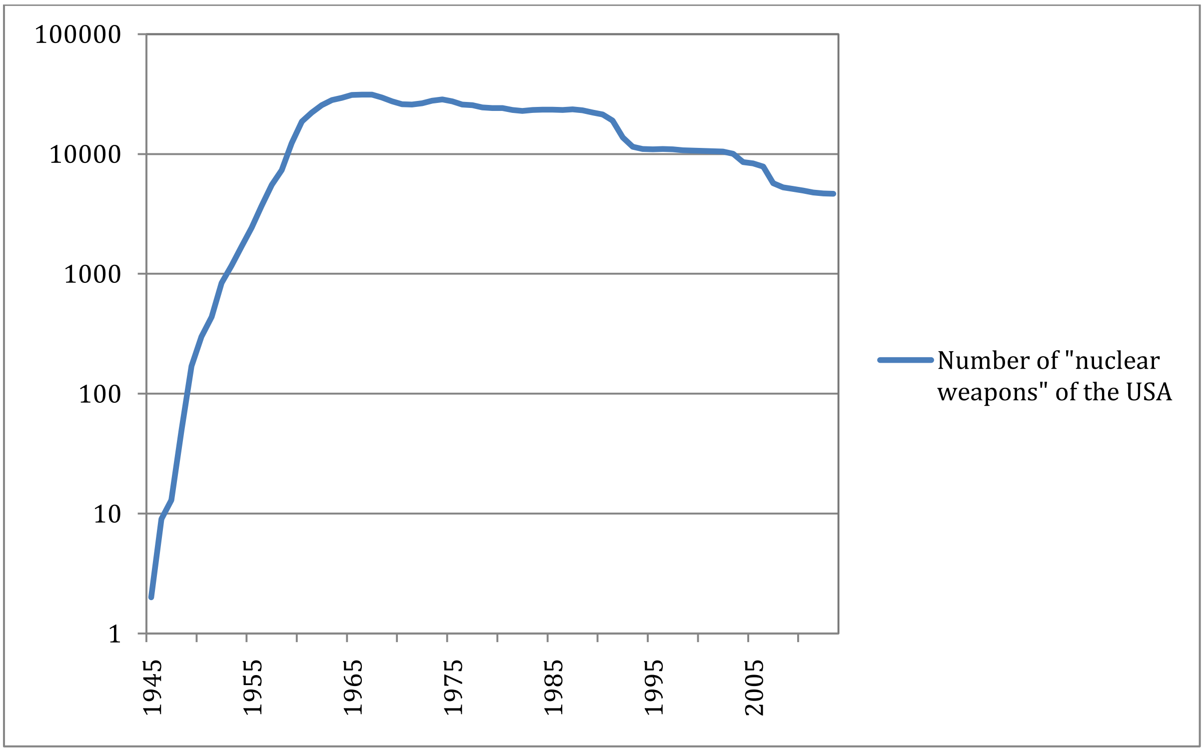


**Figure 20:** Number of “nuclear weapons” of the USA.
(Own depiction, based upon Kristensen & Norris, 2013, p. 78)

#### 3.4.1.22.3. Conclusion regarding nuclear weapons

The groundbreaking innovation nuclear weapons arose in the year 1945, as it is the year of the first explosion of an atomic bomb. It was developed very quickly during the Second World War and is perhaps the best example for R&D activities during the mentioned conflict. It spread afterwards with about two decades of strong growth of the inventories until some kind of saturation was reached. Furthermore, most other countries than the USA and Soviet Union that became atomic powers did so decades later only. Therefore, it is categorized as an innovation with a slow rise to full-scale application.

Furthermore, the idea that the construction of an extremely powerful weapon would end all wars can be seen as falsified. The idea was discussed in the context of dynamite already, which did not have the supposed effect. The same applies to nuclear weapons, as for example the Indochina War and Korean War took place soon after the first use of nuclear weapons.

### 3.4.1.23. Computer

One of the earliest meaningful predecessors of the computer is the design by Hollerith. According to van Creveld (1991), Hollerith's device was used to census the population of the USA in 1890 (p. 237). He used a system with punched cards that represented each citizen of the country and a machine could read the cards and count the number of characteristic attributes; it was so efficient that an improved version was used for the same task in 1900 (Swedin & Ferro, 2007, pp. 21–22).

#### 3.4.1.23.1. Development of the computer

Overall, the computer and its development were dependent on advances in the fields of chemistry, physics, as well as electrical engineering. Like in other cases, a certain proximity to the technological reality of the Kondratieff cycle is apparent.

In general until the end of the Second World War, calculating tasks were performed by devices provided by Hollerith's company and others, which were dependent on a large number of humans performing calculating jobs (Swedin & Ferro, 2007, p. 23). According to Raines (2011), Bush constructed the "differential analyzer" in the 1920s to deal with mathematical problems (p. 336). However, his model, like others of the time, was neither electronic nor digital (Swedin & Ferro, p. 26). Another field of complex problem solving where early computers were used was the integration of radar with weapons for fighting incoming aircraft (van Creveld, 1991, p. 238).

Boot (2007) writes that the "ENIAC" was the most important early computer. It was extremely bulky as well as heavy and produced enormous amounts of warmth. The army sponsored its development as a device for calculating in the complicated field of ballistics and bombing was needed (pp. 308–309). Swedin and Ferro (2007) write that the "ENIAC" was "electronic" and "digital" with no stored programs, however. "EDVAC" followed after "ENIAC" and featured stored programs but was only completed in 1952. Three years earlier, "EDSAC" was completed that could also store programs, being the first model to do so. In 1951, the company of Mauchly and Eckert completed "UNIVAC"; it was the "first commercial computer" (pp. XIV–XV, 41–44).
"ENIAC" and "EDVAC" were the fundament from which the modern computer arose (Boot, 2007, p. 309). However, according to Swedin and Ferro (2007), Berry and Atanasoff developed the "ABC", which was ready in 1942. "The computer was digital, used vacuum tubes, used binary numbers, used logic circuits, used refreshing memory, and had a rotating drum containing condensers to serve as memory". In 1973, a patent dispute led to the invalidation of the patent by Mauchly and Eckert for their "ENIAC" and the "ABC" was accepted as the first modern computer instead (pp. 27–30). Even though the "ENIAC" indeed traces its roots to the "ABC", the power to perform of the first named was much higher (Swedin & Ferro, 2007, p. 40).
Swedin and Ferro (2007) explain that a variety of other designs appeared as well. Among them were the ones by Zuse. Similar was the "Mark I" by Aiken, finished in 1943 and also a powerful device, superseded by the "Mark II". Neither of the mentioned had much impact on the development of the modern computer, which was mainly influenced by the "ENIAC", however (pp. 36–38). The same applies to the models "Colossus" and the "bombes" developed in Great Britain during the Second World War for dealing with German encryptions (Swedin & Ferro, 2007, pp. 33–35, 45). The next important step of the development of the computer was decreasing its size. "Transistor, integrated circuit, and microprocessor" paved the way for miniaturization, the first one was invented in 1947, the second in 1959 and the last one in the period 1969–1971 (Boot, 2007, pp. 309–310). Swedin and Ferro (2007) explain that the "transistor" replaced "vacuum tubes" and solved the problem of all their drawbacks like being large and producing warmth. The "integrated circuit" found application quickly, for example in rockets of the "Minuteman" series or for the development of equipment for space missions. The "microprocessor" in turn enabled the emergence of the "personal computer" (pp. 50–51, 67, 82–83). During the following decades, the personal computer developed and gained the role it plays today.

Important models of this process were amongst others: the “Altair 8800”, the “Apple II”, the “IBM PC”, and the “Macintosh” (Swedin & Ferro, 2007, pp. 85–100).

**Meaningful events related to the development of the computer**

1. 1904: Fleming constructs the “diode vacuum tube” (Swedin & Ferro, p. XIII).
2. 1920s: Bush builds the “differential analyzer” (Raines, 2011, p. 336).
3. 1938–1942: Atanasoff and Berry develop their device (Jewkes, Sawers & Stillerman, 1969, p. 343).
4. 1940: The “bombe” appears, an “electromechanical” device to break German encryptions (Swedin & Ferro, 2007, p. 33).
5. 1941: Zuse constructs the “Z3”, which was used for calculations related to aviation (van Creveld, 1991, p. 237).
6. 1943: “Colossus” constructed in Great Britain (Swedin & Ferro, 2007, p. XIV).
   1943: Under Aiken’s leadership, “Mark I” is constructed in the USA (Swedin & Ferro, 2007, p. 37).
   1943–1945: Mauchly and Eckert build the “ENIAC” (Boot, 2007, pp. 308–309).
7. 1945: Mauchly and Eckert start constructing “EDVAC” (Swedin & Ferro, 2007, p. XIV).
8. 1946: Publication of “‘Preliminary Discussion of the Logical Design of an Electronic Computing Instrument’” by von Neumann, Goldstine as well as Burks, they discuss the concepts of “‘stored programme’” as well as “‘conditional transfer’” (Jewkes, Sawers & Stillerman, 1969, p. 343).
9. 1947: Shockley, Bardeen and Brattain construct the “transistor” (Boot, 2007, p. 309).
10. 1949: “EDSAC” completed, “the first stored programme computer” (Jewkes, Sawers & Stillerman, 1969, p. 344).
11. 1951: Mauchly and Eckert construct “UNIVAC” (Swedin & Ferro, 2007, p. XV).
12. 1959: Kilby gets a patent regarding the “integrated circuit” (Boot, 2007, p. 310).
13. 1964: Kurtz and Kemeny construct the programming language “BASIC” (Swedin & Ferro, 2007, p. XVI).
    1964: First version of “CAD” appears (Swedin & Ferro, 2007, p. XVI).

### 3.4.1.23.2. Full-scale application of the computer

The opinion that the computer or at least the industry of electronics dominated a whole Kondratieff cycle is widespread in the community of Kondratieff cycle researchers. Väyrynen (1990) opines that the cycle ever since 1968 is driven by “telecommunications, computers, electronics, biotechnology” (p. 320). Nefiodow and Nefiodow (2014) argue that the cycle starting in the 1950s was driven by “information technology (own translation)” (p. 230). Perez (2005) argues that the “Age of Information and Telecommunication” began in 1971 (p. 57). It has to be noted that the dating of the Kondratieff cycles of the mentioned authors differs to some extent. Overall, their findings should suffice as evidence for the meaning the computer reached ever since its emergence. A rough numerical overview concerning the development of computers in the world looks as follows: from under 7,000 “electronic digital computers” in 1960 to approximatively 130,000 a decade later, to 600,000,000 ”Windows PCs” by the year 2004 (Swedin & Ferro, 2007, pp. 83, 109). However, looking at the number of personal computers only would be misleading, as microprocessors have become a part of a variety of products. Amongst them are “watches, stereos, televisions, automobiles, cell phones, pagers, microwaves” (Swedin & Ferro, 2007, p. 132).

Regarding the military meaning of the computer, the remarks above show the interconnection of its development and military needs and which role it played during the Second World War. Later on, the number of tasks performed increased. Raines (2011) writes that in the 1950s, the army of the USA started a program called “Fieldata”, where a computer dealt with tactical data. The program was discontinued a decade later, however (pp. 336–337). Nevertheless, the computer became important in many different applications. In the field of communications, “UNICOM” was a program to use computers for dealing with the data stream related to communications (Raines, 2011, p. 339). Another example is “TACFIRE” that was used for monitoring and steering artillery pieces (Raines, 2011, p. 399). Later general fields of application include according to van Creveld (1991) the automation of administration, communications, gathering data regarding enemies, automated steering of rockets, and simulating armed conflicts (pp. 239–247). Also weapons like submarines, airplanes and naval vessels are equipped to a meaningful extent with computers (van Creveld, 1991, pp. 275–278). A large field related to the computer is “cyberwar”, as Swedin and Ferro (2007) explain. It includes not only interfering enemy communications, but also bringing down networks and systems. Perhaps the most powerful weapon in this arsenal is producing an “EMP”, which knocks out devices that work with electric current (pp. 143–145). Its range can equal many hundred miles (van Creveld, 2008, p. 176). Overall, the computer has found its way into many military areas. Providing detailed information here would mean getting lost in detail. For example, Boslaugh (1999) shows its impact on the naval forces of the USA.

**3.4.1.23.3. Conclusion regarding the computer**

Overall, the computer is one of the few innovations where the military played a meaningful role from the early stages of development on (Boot, 2007, p. 310). Swedin and Ferro (2007) conclude:

> There is an obvious direct line of technological innovation from the ABC computer to the ENIAC, and then to the UNIVAC. While the Z machines, Harvard Mark I, bombes, and Colossi remain very interesting efforts, they did not substantially affect the larger story of the computer. (p. 45)

Boot (2007) sees “ENIAC” and “EDVAC” as the fundament from which the modern computer arose (p. 309). Therefore, it seems acceptable to choose the ENIAC as the origin of the computer and the year 1945 when it was completed as the corresponding year. The development to full-scale application was rather drawn out, so this innovation is categorized as a slow rise to full-scale application.

**3.4.2. Research question 2**

Research question 2 deals with the question if the emergence of groundbreaking innovations in weapons technology was similar to the emergence of general innovations over time according to Mensch (1975). Therefore, the results of this dissertation are compared to Mensch’s (1975) results. The second part elucidates the nature of the innovations in the sense how their creation was motivated or how the background of their rise looks like. A deeper understanding of their emergence is the consequence.

**3.4.2.1. Comparison to Mensch’s results**

When dealing with research question 1, the years the groundbreaking innovations in weapons technology appeared were determined. Using the results and displaying them in a similar fashion like Mensch (1975) provides a direct comparison to his findings. However, some limitations apply: firstly, the size of the sets. The set of groundbreaking innovations in weapons technology consists of 23 items. The overall set used by Mensch (1975) is much larger with 130 innovations. His set for the period starting in 1800 contains 116 elements. Secondly, some caution is advised when comparing general innovations with innovations in the area of weapons technology that have a to a meaningful extent different nature than the first named. Thirdly, Mensch (1975) uses the dates regarding the long waves by Kuznets (p. 46), which differ from the ones used in this dissertation. Nevertheless, the clusters of innovations can be compared, as they are unrelated to the used dates.

The question arises what the figure means and what can be deducted from it. Mensch (1975) looked for a clustering in the first place and considered sheer quantities of innovations of minor importance (p. 141). As can be seen, the results differ to some extent.

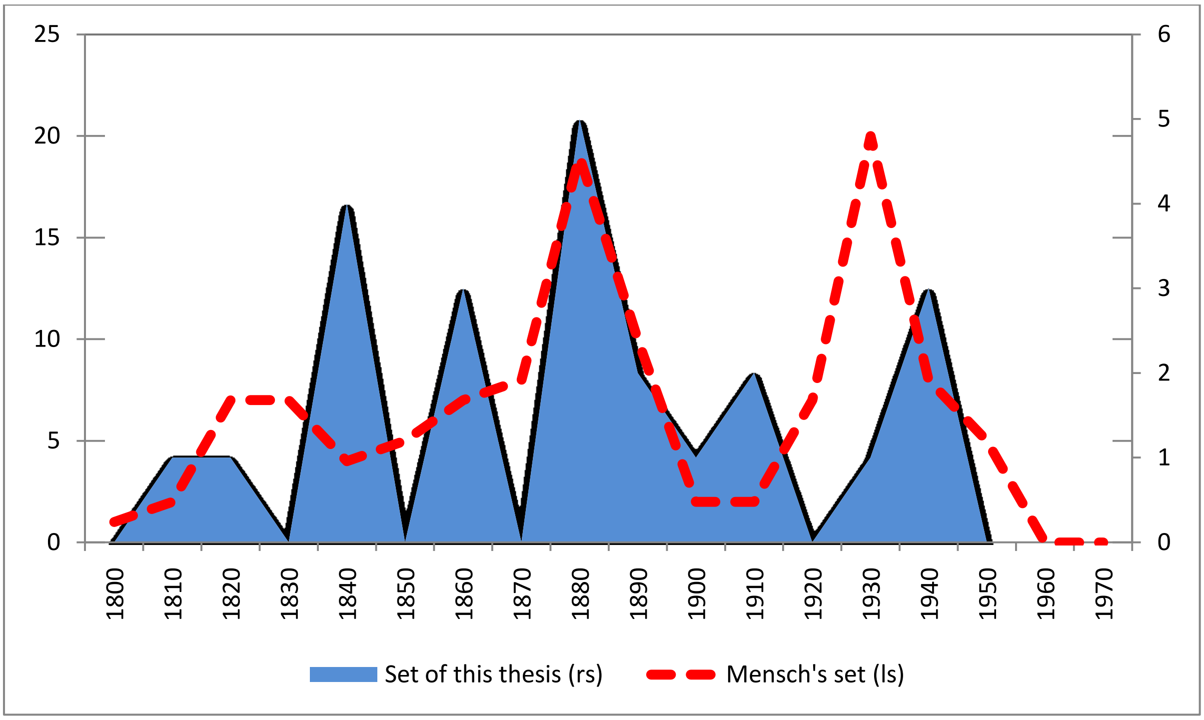


**Figure 21:** "Basis innovations" per decade according to Mensch as well as groundbreaking innovations in weapons technology per decade. (Own depiction, based upon Mensch, 1975, pp. 135–139)

Six peaks are visible concerning the set of this dissertation: 1810s–1820s, 1840s, 1860s, 1880s, 1910s as well as 1940s. Furthermore, six periods without any innovations exist: 1800s, 1830s, 1850s, 1870s, 1920s, as well as the time from the 1950s onwards. It is plausible to argue for a certain clustering. The most outstanding is the peak of the 1880s, which occurred simultaneously with Mensch's peak with the second most innovations. Furthermore, one could argue that the peak of the 1940s corresponds to the peak of Mensch's set that occurred in the 1930s and was one decade delayed. The same could be said concerning the peak of the 1840s and Mensch's peak of the 1820s–1830s. It is difficult to argue for more similarities.

A deeper understanding arises by looking closer at the innovations of the peaks and comparing the ones of this set to the ones defined by Mensch (1975): his peak of the 1820s–1830s is dominated by the areas iron and steel, railway, chemistry and telegraphy. Electricity dominated the decade of the 1840s and chemistry as well as steel the one of the 1850s. Electricity and chemistry dominated the 1860s (pp. 135–137).

The first peak of the set of this dissertation 1810s–1820s contains the railway as well as the percussion cap, a relatively simple innovation depending on a chemical compound. The peak of the 1840s of this dissertation contains the telegraph, which Mensch (1975) dated a decade earlier. Furthermore, it contains two innovations dependent on iron and steel: the breech-loading rifle and breech-loading rifled artillery. The last one is the cylindro-cononidal bullet, which is not closely related to Mensch's (1975) innovations. However, its mass production was dependent on machine tools, a feature of the Industrial Revolution in general. The peak of the 1860s contains the ironclad, screw-driven steamer, which was heavily dependent on advances in the area of iron and steel and the steam engine. The two remaining ones cartridge case and torpedo are rather related to machine tools, however.

The innovations of this set that occurred during the 1880s are smokeless powder (1884), machine gun (1884), automobile (1885), magazine (1885), as well as quick-firing artillery (1889). Mensch's (1975) peak of the 1880s is dominated by innovations from the fields of "electrical engineering (own translation)" as well as "chemistry (own translation)" (pp. 136–137). A certain relationship between the automobile and electrical engineering and chemistry exists. Undoubtedly, smokeless powder is related to the field of chemistry. The machine gun by Maxim was also dependent on smokeless powder for a reliable operation. The same is true for quick-firing artillery. Only the magazine is by and large unrelated, however. The innovations of the cluster of the 1880s are heavily dependent on the chemical innovation smokeless powder.

The peak of the 1910s contains the tank and gas. Both reflect the general innovative activity of the preceding decades illustrated by Mensch (1975). The peak of the 1940s of the set of this dissertation consists of the ballistic missile (1942), nuclear weapons (1945), as well as the computer (1945). Mensch's (1975) peak of the 1930s (pp. 138–139) consists of different innovations and it is difficult to spot a dominating area. However, Metz (2006) uses a different data set and finds that chemistry played a meaningful role in the 1930s (p. 95). Indeed, chemistry is important for example for

the fuel of ballistic missiles and the materials used for their construction. Also for nuclear weapons, advances in chemistry were meaningful and important developments took place in the 1930s, as mentioned above. Also the development of the computer was dependent on advances in chemistry as well. Regarding the development of ballistic missiles and nuclear weapons, important steps took place during the 1930s already. Therefore, a qualitative connection exists between the peak of the 1940s of this dissertation and the one by Mensch (1975) of the 1930s as well.
Overall, from a qualitative perspective, an obvious general link between the innovations of this dissertation and the ones by Mensch (1975) exists. However, it is difficult to detect a close or orthodox relationship, which applies to all cases. Moreover, it is difficult to find a certain pattern, which describes the temporal relationship concerning their occurrence.

#### 3.4.2.2. Motivation concerning the emergence of the groundbreaking innovations in weapons technology

From a general economic perspective, weapons are absurd, as they do not produce anything positive but destroy goods that have a utility. Their only benefits are the possibility to destroy, kill, as well as to deter. They are not only unable to produce goods and services but also are they able to destroy productive capital and usually destruction is their own fate (von Ciriacy-Wantrup, 1936, pp. 287, 364). Furthermore, the law of supply and demand does not apply to them during belligerent times and only the end of the war comes along with a decrease in demand for them (von Ciriacy-Wantrup, 1936, p. 364).
However, it is clear that the inventor working on a certain weapon might of course have economic motives, as he may be able to sell his innovation later on. Nevertheless, he does not work on something that produces goods and services for the benefit of mankind, which would be a useful task. Rather, he accepts human suffering and large-scale destruction for his personal gain. For single persons, groups, states, as well as groups of states, producing and dealing with weapons might indeed be economically viable. Looking at the world as a whole, it might be more attractive to use the resources for productive purposes instead.
For a better understanding of the nature of the groundbreaking innovations in weapons technology, the analysis of the motivation concerning their creation follows. However, certain limitations apply to this section: a strict differentiation is not possible in many cases. For example, ideas of a device with similarities to the modern machine gun were around for centuries. The final design by Maxim was his idiosyncratic idea,

however. Furthermore, many descriptions of the background regarding the creation of the innovations are something like anecdotal evidence with limited trustworthiness. Overall, this section provides important insights but is necessarily somewhat vague.
In general, four major groups can be formed: the first group consists of ideas that were around for many centuries already but could not be constructed adequately before. Examples are the breech-loading rifle, breech-loading, rifled artillery, as well as the cartridge case. The second group consists of solutions for defined existing problems. Examples are the modern use of gas and the tank that was created to overcome the stalemate during the First World War. Another example is the computer that was constructed to deal with difficult calculating problems related to the military and war. Also nuclear weapons fit into this group. The third group consists of innovations that are idiosyncratic works of their creators. Examples are the Maxim machine gun and the cylindro-conoidal bullet. Some innovations included in the set of this dissertation are not weapons per se but are general technological innovations. However, they had an important influence on warfare. They are: railway, telegraph, automobile, wireless communications, airplane, as well as radar. They form the fourth group of general innovations.

**3.4.2.2.1. Old idea**

The cases, which fit relatively well into this category are: breech-loading rifle, breech-loading, rifled artillery, as well as the cartridge case. Early designs of breech-loading rifles date back about five centuries (Held, 1970, p. 61) but only the design by Dreyse can be seen as the innovation in the narrower sense. Artillery that was breech-loading appeared about 600, rifled artillery about 350 years ago (Fuller, 1998, p. 130). However, only the devices by Wahrendorff and Cavalli of the year 1846 can be seen as the true innovation. A cartridge in the broader sense dates back at least three centuries. In the narrower sense however, it only exists ever since Berdan and Boxer developed their designs about 160 years ago. For the mentioned cases, it seems fair to assume that their creators worked on the old problem and were finally able to solve it adequately. In most cases, people tried to solve the old problems ever since the first design appeared but were unable to so until the mentioned versions arose.

#### 3.4.2.2.2. Solution to a defined problem

The tank, gas, nuclear weapons, and the computer are innovations that were constructed for dealing with a defined problem. Gas was used in Ancient Greece 2,500 years ago already (Brodie & Brodie, 1973, p.15). It was only used on a large scale during the First World War to break the stalemate, however. As described above, the development of the modern tank started briefly before the First World War only and it was finished during the named war. Ellis (1986) sees it as an attempt for dealing with the stalemate during the First World War (pp. 167–168). As the part above dealing with the computer shows, its development was somewhat complicated. Most of the early designs were related to the Second World War and/ or military calculation needs of many kinds. Also nuclear weapons fit into this category, as their development was spurred during the Second World War and they were finally decisive.

#### 3.4.2.2.3. Idiosyncratic work

Maxim machine gun and cylindro-conoidal bullet are two innovations that are the idiosyncratic work of single persons. This is unconditionally true for the Maxim machine gun. For the cylindro-conoidal bullet, it is true with a constraint only: the inventor in the narrower sense was Norton in 1823 (Fuller, 1998, p. 112), while Minié produced his design in 1849 (Fuller, 1998, p. 113). The latter is accepted as the pivotal innovation in this dissertation. Monetary interests might have been Maxim's motivation for the construction of the Maxim machine gun (Hutchinson, 1938, pp. 48–49, as cited in Ellis, 1986, pp. 33–34). Norton was influenced by his observation of how a "blow tube" and the corresponding ammunition was used and adopted the operating principle (Robertson, 1921, p. 193; as cited in Fuller, 1998, p. 128). Also the early work leading to the innovation ballistic missile fits into this group: single persons like Goddard, but also the rocket societies in different countries contributed meaningfully. Main driver might have been personal interest and only at a later stage the military took over.

#### 3.4.2.2.4. General innovations

The innovations included in the set of this dissertation that are not weapons per se are: railway, telegraph, automobile, wireless communications, airplane, as well as radar. As described in the empirical part, the development of most of them was drawn out with many intermediate stages of development. An example is the airplane in the narrower sense, which took a century to complete. The prestige of being the first to solve such a problem should have been a meaningful driver for the creators. The airplane by the Wright brothers, which was the first working design in the narrower sense, remains a milestone until today. Apart from that or other minor reasons, their creators' main motivation should have been monetary in almost all cases.

#### 3.4.2.2.5. Conclusion regarding the motivation

The nature and emergence of the innovations of the set of this dissertation are different. Some innovations are weapons per se, others general innovations that affected warfare meaningfully. The last named affected the economic development in general meaningfully as well. From the field of weapons in the narrower sense, some exist as ideas for centuries already, while working models appeared much later only. Others were developed for solving a certain problem or arose as idiosyncratic work of individuals. It seems fair to conclude that the set of groundbreaking innovations in weapons technology of this dissertation contains items that vary meaningfully with regard to their nature and background of emergence concerning their creation.

## 3.5. The alternative set by Dupuy

As mentioned above, Mensch's (1975) findings experienced severe critique. Later examinations with different data sets mostly support his findings, however. Therefore, a set that differs from the sample of this dissertation is analyzed as well.

**Table 4:** The Dupuy sample since 1790. (Own depiction, based upon Dupuy, 1990, pp. 292–294, 296–298).

| | **Innovation** | **Date** |
|---|---|---|
| 1. | Percussion cap | about 1815 |
| 2. | Telegraph | about 1840 |
| 3. | Conoidal rifle bullet | 1849–1860 |
| 4. | Breech-loading rifle | 1848–1864 |
| 5. | Breech-loading rifled artillery | 1845–1870 |
| 6. | Barbed wire | about 1874 |
| 7. | Maxim machine gun | 1883 |
| 8. | Smokeless powder | 1885 |
| 9. | High-explosive shell | 1886 |
| 10. | Bolt-operated magazine rifle | about 1895 |
| 11. | Internal combustion engine | 1887 |
| 12. | Recoil mechanism, quick-firing artillery | 1890–1910 |
| 13. | Observation aircraft | 1907 to First World War |
| 14. | Photography | about First World War |
| 15. | Field telephone | about First World War |
| 16. | Voice radio | about First World War |
| 17. | Tank | 1916 |
| 18. | Fighter-bomber | 1917 |
| 19. | Radar (defensive use) | 1938 |
| 20. | Inertial and electronic guidance | (?) [1940s/ Second World War] |
| 21. | Computers/ automatic data processing | 1940 |
| 22. | Radar (offensive use) | 1944 |
| 23. | Ballistic missile | 1944 |
| 24. | Atomic bomb | 1945 |
| 25. | Earth satellites in spaces | (?) [1957, Sputnik] |

Dupuy (1990) presents a set of "eighteen significant developments in weapons and their lethality" as well as one that covers "nineteen major technological advances that seem to have been truly revolutionary in their influence on warfare" (pp. 290–298). The great advantage of Dupuy's (1990) sample is that it is unrelated to research concerning the Kondratieff cycle. Both sets combined offer a good sample of 25 items, which is comparable to the one used in this dissertation. Table 4 shows it for the time frame analyzed in this dissertation; items, which have appeared earlier, have been removed. Furthermore, the items "electronic communication" as well as "radar" were broken down to their applications, in the case of "radar" "defensive use" and "offensive use". In comparison to the set of this dissertation, it contains two more items overall. At the same time, it covers 16 items also included in the former. From a qualitative perspective, the most important difference to the set of this dissertation is that naval innovations are missing. The set of this dissertation includes the ironclad, screw-driven steamer (1860), the torpedo (1866), as well as the submarine (1897). By contrast, Dupuy's (1990) set includes items like "barbed wire" and "photography", which the author of this dissertation considers less important. They played a role for sure but their importance cannot be compared to for example nuclear weapons.

A major advantage is that Dupuy (1990) offers dates for the single items as well and therefore it is not only an unrelated sample, but also an unrelated set of corresponding dates. However, minor adjustments were necessary to make the sample comparable. Firstly, in the cases marked with a question mark in the table above, Dupuy (1990) did not mention a certain year and the author of this dissertation had to perform this, which dilutes the unrelatedness of this sample to some extent. However, this applies only for two cases, numbers 20 and 25. Secondly, Dupuy (1990) mentions in some cases time frames instead of single years. For the analysis of his set, always the first years were used.

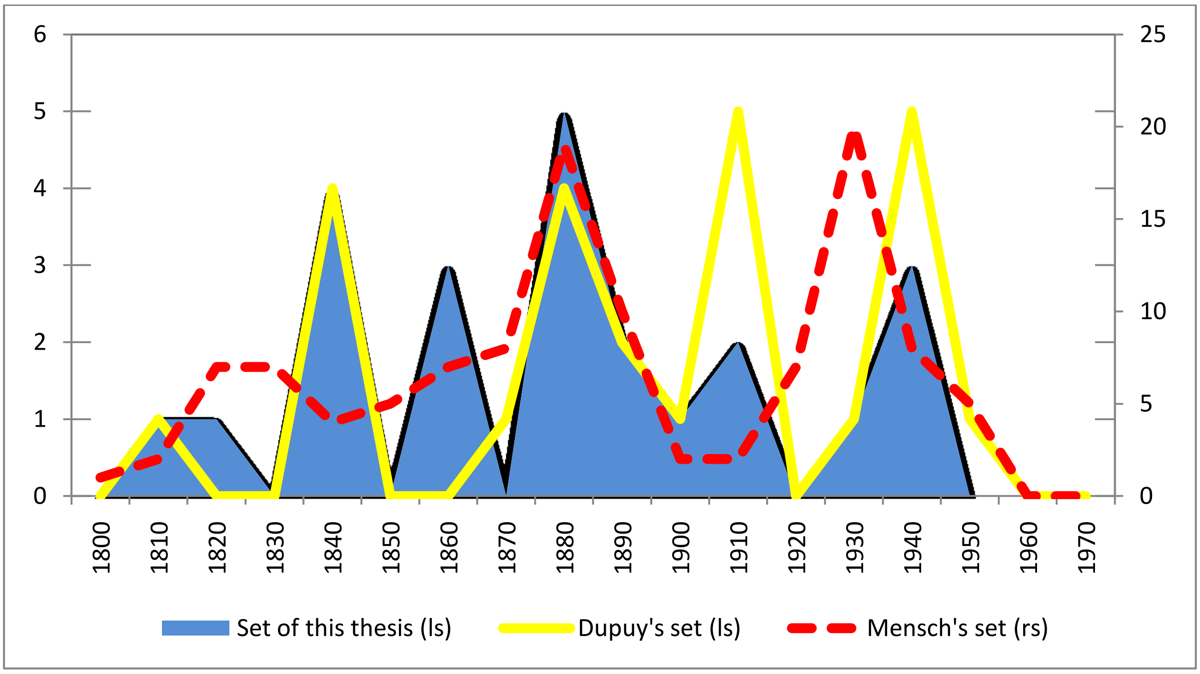


**Figure 22:** Comparison of the sets by Mensch, Dupuy, as well as the one of this dissertation. (Own depiction, based upon Mensch, 1975, pp. 135–139 and Dupuy, 1990, pp. 292–294, 296–298)

The figure above compares the set by Dupuy (1990) to the one by Mensch (1975) and the one of this dissertation. Also in this case, a certain divergence to the one by Mensch (1975) can be observed, while similarity to the one of this dissertation exists: all peaks of the set of this dissertation are visible as well, except for the one of the 1860s. The qualitative explanation is by and large the absence of naval innovations in Dupuy's (1990) set. The three innovations of the set of this dissertation in the 1860s are: ironclad, screw-driven steamer (1860), the torpedo (1866), as well as the cartridge case (1866). The one of the 1810s–1820s of this dissertation has an equivalent here that only covers the 1810s with one innovation. Overall, the number of observations per peak differs also to some extent.

Dupuy (1990) makes the following observations regarding periods the major advances occur: he mentions the clustering in the 1840s as well as the one in the 1880s to 1890s. The innovations of the 19th century appeared during peaceful times with a lag of about 15 years to the last major war. Possible explanations include financial constraints or time needed for development and testing. During the 20th century, the clusters are linked to the First and Second World War. However, the advances are rooted in the years of peace before the war. War can be seen as the force for finally finishing the development (pp. 299–300).

Undoubtably, Dupuy (1990) makes some valid points. For explaining the pattern of the emergence of innovations in weapons technology during the 20th century, his remarks are by and large accepted by the author of this dissertation. However, his remarks are unsatisfactory for the 19th century. His lag of about one and a half decade that comes along with frictions from the last war seems plausible at first glance. However, when looking closer certain problems become visible. We accept the year 1815 as the end of the major hostilities around the Napoleonic Wars and the War of 1812. We look at his cluster of the 1840s only and find that, using his dates, they all appeared 25 to 34 years after the year 1815, which is far in excess of 15 years. Furthermore, the cylindro-conoidal bullet is one of the innovations of the 1840s. As discussed above, the invention occurred in 1823 (Fuller, 1998, p.112). A relationship of whatever kind to the belligerent period ending in 1815 is hard to find. Another example is the Maxim machine gun, which Dupuy (1990) includes in the cluster of the 1880s. As discussed above, Maxim's design was his idiosyncratic work and is unrelated to the American Civil War and Franco-Prussian War, as well as to models in use during the mentioned wars.

## 3.6. Conclusion from the empirical part

Overall, the results are not as distinct as in the case of Mensch's (1975) study. Nevertheless, a differentiated picture has arisen. The innovations have different backgrounds and vary to some extent in their nature as some are at the same time general innovations like the railway. Furthermore, a certain similarity to Mensch's (1975) pattern exists. Below follow remarks regarding the link to the long wave, major wars, as well as the general technological reality.

### 3.6.1. Groundbreaking innovations in weapons technology and the long wave

In general, the framework constructed for this dissertation consisting of long waves dated by using the 10-year rolling return of the S&P 500, major wars as determined by Levy (1983) in combination with the technological reality according to Nefiodow (1990) and Nefiodow and Nefiodow (2014) is a solid part of the orthodox Kondratieff cycle. Regarding the first research question, the dissertation provides a differentiated picture. The dates for the lower turning points of the long wave and of the clusters of the emergence of groundbreaking innovations in weapons technology are as follows:

**Table 5:** The long waves of this dissertation and their respective dates.

| Long wave | Start | End |
|---|---|---|
| 1 | n/a | 1840s (1842) |
| 2 | 1840s (1842) | 1890s (1896) |
| 3 | 1890s (1896) | 1930s (1938) |
| 4 | 1930s (1938) | 1970s (1974) |
| 5 | 1970s (1974) | 2000s (2008) |

**Table 6:** Clusters of groundbreaking innovations in weapons technology.

| Cluster | Date | Number of innovations |
|---|---|---|
| 1 | 1810s/1820s | 2 |
| 2 | 1840s | 4 |
| 3 | 1860s | 3 |
| 4 | 1880s | 5 |
| 5 | 1910s | 2 |
| 6 | 1940s | 2 |

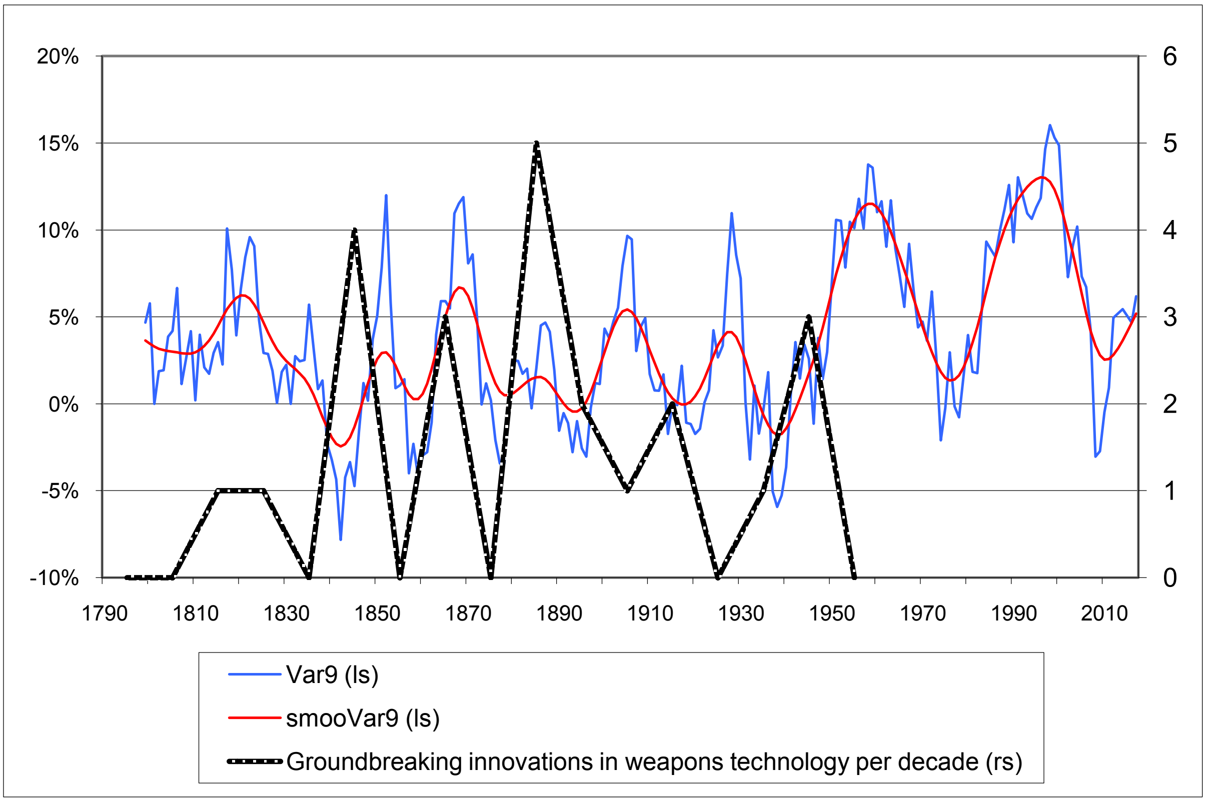


**Figure 23:** 10-year rolling return of the S&P 500, 1789–2017 and groundbreaking innovations in weapons technology per decade. (Own depiction, based upon Allianz, 2010. Calculations based upon https://stooq.com/q/d/?s=^spx&i=y. Smoothed with a Hodrick-Prescott filter, λ=100.

Even though the situation is not as clear as in the case of Mensch's (1975) study, it cannot falsify the theory stated above. The distinct peaks of the 1840s, 1880s, as well as 1940s are close to turning points of the long wave, which is in line with Mensch's (1975) results and his adopted metamorphosis model, as explained above in part 2. The peaks of the 1910s and 1940s are at in line with the rise of the R&D sector and the expectation that the World Wars were triggers for finishing weapons that were already under construction earlier on. The remaining peaks of the 1810s/1820s and 1860s do not fit very well. However, they are temporally closely related to major wars and it seems plausible to argue for an influence of the wars, as discussed above.

**3.6.2. Groundbreaking innovations in weapons technology and major wars**

Regarding the question how the emergence of groundbreaking innovations in weapons technology is temporally related to major wars as defined above building upon the work of Levy (1983), tables 7 and 8 show that the majority of innovations arose during years when no major war took place.

**Table 7**: Emergence of groundbreaking innovations in weapons technology in Great Britain during war years/ no war years. (Percentages rounded)

| Great Britain | Number of innovations | Percentage of innovations |
|---|---|---|
| War years | 5 | 21,7% |
| No war years | 18 | 78,3% |

**Table 8**: Emergence of groundbreaking innovations in weapons technology in the USA during war years/ no war years. (Percentages rounded)

| USA | Number of innovations | Percentage of innovations |
|---|---|---|
| War years | 5 | 21,7% |
| No war years | 18 | 78,3% |

None of the groundbreaking innovations in weapons technology that emerged during the 19th century did so during a war year. Concerning the situation in Great Britain during the 19th century, the peak in innovative activity of the 1810s–1820s consists of two items: the percussion cap (1816) as well as the railway (1825). The railway is a decade away from the end of the Napoleonic Wars, while the percussion cap followed a year after the Battle of Waterloo. While there was no meaningful war around 1840, the peak of the 1860s occurred between the Crimean War 1853–1856 as well as the Franco-Prussian War 1870–1871. Regarding the USA, the percussion cap followed soon after the War of 1812 1812–1814. The peak of the 1860s is temporally close to the American Civil War 1861–1864. Like in the case of Great Britain, the peak of the 1840s is temporally not related to a major war. No war with the participation of both countries occurred that is temporally related to the peak in innovative activity of the 1880s. The result goes well with the theory developed above, which assumed a certain, undefined influence of war on military technology during the 19th century. However, a strong link like in the 20th century was not expected.

All innovations that emerged during war years did so during the First and Second World War. The five innovations are: gas, tank, ballistic missile, nuclear weapons, as well as the computer. Therefore, the theory developed above could not be falsified regarding the 20th century. Rather, the theory describes well the close connection between groundbreaking innovations in weapons technology and wars during the first half of the 20th century. Possible reasons are the factors discussed above: rise of the R&D sector, totalization of war, as well as the increasing power of the state.

### 3.6.3. Groundbreaking innovations in weapons technology and their rise to full-scale application

Concerning the question how the innovations reached full-scale application, the following applies: some innovations did so like general innovations of the Kondratieff cycle in a slow manner, some were paradigm changes and gas was the only one that showed up briefly and more or less disappeared again. Table 9 summarizes the insights. It has to be noted that the railway, automobile as well as computer are closely related to the technological reality according to Nefiodow (1990) as well as Nefiodow and Nefiodow (2014).

**Table 9:** Categorization of the groundbreaking innovations in weapons technology regarding their rise to full-scale application.

| **Innovation** | **Paradigm change** | **Slow rise** | **Other** |
|---|---|---|---|
| Percussion cap | | x | |
| Railway | | x | |
| Breech-loading rifle | | x | |
| Telegraph | | x | |
| Breech-loading, rifled artillery | | x | |
| Cylindro-conoidal bullet | x | | |
| Ironclad, screw-driven steamer | x | | |
| Cartridge case | x | | |
| Torpedo | | x | |
| Smokeless powder | x | | |

| Innovation | Paradigm change | Slow rise | Other |
|---|---|---|---|
| Machine gun | | x | |
| Automobile | | x | |
| Magazine | x | | |
| Quick-firing artillery | x | | |
| Submarine | | x | |
| Wireless communication | | x | |
| Airplane | | x | |
| Gas | | | x |
| Tank | | x | |
| Radar | x | | |
| Ballistic missile | | x | |
| Nuclear weapons | | x | |
| Computer | | x | |

#### 3.6.4. Groundbreaking innovations in weapons technology and the general technological reality

Table 10 illustrates the relationship between the groundbreaking innovations in weapons technology and the technological reality of the Kondratieff cycle by applying the year of the former's emergence to the different periods of the latter according to Nefiodow (1990) and Nefiodow and Nefiodow (2014). It is a main insight from this dissertation as it shows during which technological reality the groundbreaking innovations in weapons technology have arisen.

Concerning the question how the innovations are related to the technological reality of the period under analysis, the following applies: from a qualitative perspective it is clear that in fact almost all of the groundbreaking innovations are related to the technological reality of the Kondratieff cycle and to the advances related to the Industrial Revolution and the ones that took place afterwards.

**Table 10:** Technological reality of the Kondratieff cycle and groundbreaking innovations in weapons technology. (Own depiction, based upon Nefiodow, 1990, and Nefiodow and Nefiodow, 2014)

| Cycle and period | Basis innovation | Groundbreaking innovation and year |
|---|---|---|
| 1. (1790–1850) | Steam engine | - Percussion cap, 1816<br>- Railway, 1825<br>- Breech-loading rifle, 1840<br>- Telegraph, 1844<br>- Breech-loading, rifled artillery, 1846<br>- Cylindro-conoidal bullet, 1849 |
| 2. (1850–1900) | Railway,<br>Bessemer converter | - Ironclad, screw-driven steamer, 1860<br>- Cartridge case, 1866<br>- Torpedo, 1866<br>- Smokeless powder, 1884<br>- Machine gun, 1884<br>- Automobile, 1885<br>- Magazine, 1886<br>- Quick-firing artillery, 1889<br>- Submarine, 1897<br>- Wireless communication, 1899 |
| 3. (1900–1939) | Electrical engineering and chemical process technology | - Airplane, 1903<br>- Gas, 1915<br>- Tank, 1916<br>- Radar, 1935 |
| 4. (1945–1979) | Automobile | - Ballistic missile, 1942<br>- Nuclear weapons, 1945<br>- Computer, 1945 |
| 5. (1950s–2000s) | Information technology | |

However, the connection is relatively loose. The one mentioned by Schumpeter (2008) concerning steel and artillery (p. 367) mentioned above is representative: also the ironclad was dependent on steel, smokeless powder and gas on the advances in chemistry and wireless communications as well as radar on the advances in the field of electricity. Machines and machine tools played an important role for the large-scale production of standardized items like percussion caps, breech-loading rifles, cylindro-conoidal bullets, and cartridges. However, arguing for a closer relationship and deducting groundbreaking innovations in weapons technology in an orthodox manner from each technological reality seems untenable. Also Nefiodow and Nefiodow's (2014) suggestion of the influence of information technology on military materiel (p. 204) mentioned above is rather an improvement of existing groundbreaking innovations in weapons technology.

# 4. Concluding part

Returning to the remarks by Schumpeter (2008) and Nefiodow and Nefiodow (2014) mentioned in the beginning, the author considers the differentiated picture that arose as the most important contribution of this dissertation. Starting with the meaning of this topic both for research and practice, the chapter "on state, economy, and war" illustrates the reality of a war economy with the heavy interventions by the state that came along with it especially since the First World War. In general, major wars have been accompanied by strong price increases during the last two centuries, which usually represent the price tops of the Kondratieff cycle. It becomes very clear that normal economic life is heavily disturbed by belligerent times and that also the emergence of technological innovations has changed its nature at least ever since the First World War. Especially the rise of the R&D sector is noteworthy.

The focus of this dissertation is on the countries Great Britain and the USA as the most powerful ones on a global scale of the period under analysis. Concerning the general technological reality, it became clear that they were economies that profited the most from the technological advances of the last two centuries. The other elements of this dissertation are: major wars, the technological reality, as well as the dates of the long waves determined by using a 10-year rolling return of the S&P 500 from 1789 to 2017. A selection procedure with a minimal amount of arbitrariness selects wars with a high impact by building upon Levy (1983). Nefiodow (1990) and Nefiodow and Nefiodow (2014) provide a solid definition of the technological reality. The amount of arbitrariness regarding the construction of the used parts of the orthodox Kondratieff cycle is therefore as low as possible. The obtained results concerning the dates of the long waves by using the 10-year rolling return of the S&P 500 yielded results that are almost identical to the ones of other researchers in the field using different data.

The general theoretical part contains the necessary definitions, the reconstruction of certain parts of the orthodox Kondratieff cycle, as well as the determination of the set of groundbreaking innovations in weapons technology. Furthermore, it describes the interrelationship between state, economy, and war and summarizes the relevant existing literature. Apart from Kondratieff's orthodox work, insights combining the Kondratieff cycle and war as well as the Kondratieff cycle and technology are presented. From the field of peace research, Väyrynen's contribution is outstanding. He argues for a close connection between the Kondratieff cycle and weapons technology (Väyrynen, 1983a, p. 152). Military literature finally contributes little to the research questions per se. Clausewitz (1980) as one of the military classics discusses the topic rather on a general level. Relatively recent military authors writing on weapons technology use categorizations that reflect the technological reality of the Kondratieff cycle closely. Examples are Fuller (1998) and Boot (2007).

Finally, the construction of a theory explaining the emergence of groundbreaking innovations in weapons technology based upon the insights of the existing literature follows. It is split in two parts: the first one deals with the 19th century and the second one with the 20th century. The former argues for a certain relationship between the clusters of general innovations that Mensch (1975) found and ones in weapons technology. The latter accepts the rising importance of the R&D sector during the last century and argues for a clustering around the two World Wars.

The empirical part presents the research questions, methods, the target group, as well as the limitations that apply. Afterwards, the analysis of the 23 innovations follows to answer the first research question. From a qualitative perspective, it becomes clear that the groundbreaking innovations in weapons technology are loosely related to the general technological development but that an orthodox relationship does not exist. Furthermore, the detailed descriptions of the development of the single innovations provide a good understanding of their nature, their emergence and a verifiability of the determined dates. Regarding their rise to full-scale application, some innovations arose slowly over time, while others were something like paradigm changes.

Using the results of the empirical part dealing with the first research question makes possible dealing with the second research question. A figure displaying the number of innovations per decade enables a visualization of the result and also a direct comparison to Mensch's (1975) result, which deals with general innovations. It becomes clear that the two patterns vary to some extent. The two similarities are: the peak of the 1880s, which can be found in both sets. Mensch's (1975) peak of the 1930s has a corresponding one in the set of this dissertation in 1940. In fact, all three innovations of this dissertation that form the peak of the 1940s were dependent on advances in chemistry, which according to Metz (2006) played a meaningful role in the 1930s concerning innovative activity (p. 95). Furthermore, many important contributions to the innovations ballistic missile (1942) and nuclear weapons (1945) took place in the 1930s already.

To check the results of this dissertation, a second set is used for comparison. It is the one by Dupuy (1990) and displays by and large a similar picture as the one of this dissertation. However, some differences exist as well. The most important one is the missing cluster of the 1860s, which can by and large be explained by the absence of naval innovations in Dupuy's (1990) set. Moreover, his set varies to some extent from the one by Mensch (1975) as well. Overall, the results of this dissertation could not be falsified by the Dupuy (1990) set but are rather supported by it.

A deeper understanding of the heterogeneity of the set of innovations arises from the chapter dealing with the background of the innovations and the motivation regarding their construction. It becomes clear quickly that the 23 innovations of this dissertation have a meaningfully different nature. Six of them are not weapons per se, which is the first meaningful difference. However, as they had an important influence on war and warfare, they have to be included. They are: railway, telegraph, automobile, wireless communications, airplane, as well as radar. The remaining innovations can roughly be grouped in three major groups: old idea, solution to a defined problem, idiosyncratic work. The first group contains ideas that were around for centuries and many people tried to solve the related problems until finally someone was able to do so. The solutions to a defined problem are weapons that arose during the First and Second World War only. The idiosyncratic ones are the work of individuals that arose like in the case of the cylindro-conoidal bullet from a personal observation by the inventor. Overall, the different natures of the innovations fit well together with the pattern of the emergence of the innovations: the result is rather a random pattern of clusters loosely related to the ones of general innovations at least for the 19th century. The pattern of the 20th century with the peaks of the 1910s (First World War) and 1940s (Second World War) fits well together with the fact that the innovations from the group "solution to a defined problem" arose in 1915 (gas), 1916 (tank), and 1945 (computer and nuclear weapons). Developing or at least finishing arms already under development to make them ready for usage and having an advantage during the war going on became important. The rise of the R&D sector is a closely related and intertwined development.

Overall, the results suggest that groundbreaking innovations in weapons technology arise to some extent differently than general innovations. The reason might be their different nature. It might be safe to say that by and large groundbreaking innovations in weapons technology are linked to the general technological development of the Kondratieff cycle. However, there is not necessarily the close connection as in the case of steel and artillery pieces as mentioned by Schumpeter (2008) and discussed in the introduction. Even though this dissertation is not based upon the orthodox Kondratieff cycle, two parts of it could be replicated. Firstly, the dates of the troughs determined in this dissertation by using the 10-year rolling return of the S&P 500 are by and large identical to the dates used by most researchers in the field including Kondratieff himself. Secondly, the part dealing with the influence of war on the economy stresses the meaning of strong price increases during war. All peaks of the Kondratieff cycle of the time frame covered by Kondratieff witnessed large wars and price spikes. Independently of cause and effect regarding the occurrence of wars, they triggered strong price increases.

## 4.1. Implications for further research

The results of this dissertation may be a starting point for further research. In general, it is interesting to see if the theory of this dissertation can be falsified. A variety of tests seems possible. One possibility is the analysis of another set of innovations. The existing literature regarding general innovations provides many examples how later research checked, refined, or improved preceding work. For example, Kleinknecht and van der Panne (2006) suggest a "weighting procedure" when dealing with different sets of innovations to take into account the different importance they have (pp. 120–121). Furthermore, if the categorization by Mensch (1975) is used, it might be interesting to construct a set of "improvement innovations (own translation)" and perform the research of this dissertation. The results should enable a deeper understanding of the innovation process.

Furthermore, a totally different access to the topic might bring useful insights as well: the analysis of general changes in warfare regarding strategy and tactics over time. Looking for the emergence of the later on paradigms, analyzing their rise to full-scale application, as well as their decline later on represents an interesting piece of research. In combination with the results of this thesis it would help to work on van Creveld's (1991) "theory of the relationship between technology and war" (p. 323).

Regarding the set of groundbreaking innovations in weapons technology, the offbeat nature of many innovations supports the usefulness of studies that provide detailed information on single innovations like Gray (1975) in the field of the torpedo or Ellis (1986) regarding the machine gun. Further studies regarding other groundbreaking innovations would help to understand their development better.

## 4.2. Implications for practice

The most important key take-away is to see once again how many resources war and armament have used up and wasted alone during the time frame covered by this dissertation. The economic disruptions including the difficult supply situation of the population with consumer goods illustrates the suffering of the people. Moreover, the amount of personal suffering from destruction and violence of the wars can only be estimated. Assuming a use of the factors of production used for destructive purposes over the last two centuries in the area of productive purposes or health care instead, another reality of the world could have been possible. However, as mentioned in the very beginning, aggression seems to be a trait intimately linked to mankind.

For many observers, the utility of cycles lies in the possible predictability of the future. However, as the critics of the orthodox Kondratieff cycle show, a strong regularity does not exist. Nevertheless, a better understanding of the past and its developments should enable a better judgment regarding recent developments and what could lie ahead. The most important insight in this regard is that not every aspect of the Kondratieff cycle should be rejected per se.

From a qualitative perspective, this dissertation shows that the most important wars of the last two centuries are temporally connected to strong price increases, which supports Kondratieff's suggestion regarding the occurrence of wars. This is valid even until the end of the period covered with the Vietnam War concerning the USA, even though casualty numbers were relatively low compared to for example the First World War. Those who expected inflationary times until about 1980 were right but those who expected a major conflict like the First World War were fortunately wrong. As most commodity prices bottomed out around the year 2000 and are despite meaningful corrections still meaningfully elevated, the world might indeed experience another peak in wholesale prices and casualties during the next two decades, if the forecast is based upon the history of the last two centuries.

Regarding the technology utilized during the next large conflict, information technology might be heavily involved. This is what should be expected when basing the forecast on the results of this dissertation: groundbreaking innovations in weapons technology are loosely related to the general technological reality. Also van Creveld (2015) opines that cyberwar is probably "inevitable" (pp. 123–124).

The author closes this dissertation by expressing his hopes for a more peaceful world and R&D expenditure that helps to solve problems in the areas of environmental destruction, diseases, as well as health care. A related hope concerns the peaceful settlement of conflicts in the world, which would not only mitigate the amount of destruction and sorrow that comes along with war but would free resources for productive uses as well. Van Creveld (2015) writes: "… the best war is that which is never fought (p. 17)". There is nothing left to be added.

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