
# World War II

Course No: B03-017
Credit: 3 PDH

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## Introduction

Many technological advances come about due to military necessity. This was true in ancient Greece and ancient Rome and is still true today. World War II did not just begin. There was a lead up to the beginning of hostilities that began after World War I ended. During this time, the importance of the airplane and the tank increased and coding methods were developed. Radar existed before the war, but the radar systems in service at the end of the war did not resemble the radar at the beginning of the war.

Developments during the war led to the invention of things we know well today. The Germans developed the V-1 and the V-2 weapons that were the forerunners of the cruise missile and ballistic missile respectively. Atomic research accelerated during the war as Germany and the United States both were developing atomic weapons. The successful research and development efforts were ones that had the support of the senior leadership.

When World War I ended, war was thought of as defensive over offensive in many ways. Trench warfare was used widely in the war. Defensive concepts were at the root of the Maginot Line between France and Germany, as well as the Siegfried Line between the wars. The improvement of tanks and planes in the interwar years shifted the balance to where wars could be more offensive.

The developments of World War II had a drastic and lasting effect on life after the war. The political alignment, social structure, and international relations were changed for the rest of the 20$^{th}$ century. Technology found new uses as consumer products after the war. Others were exploited during the political competitions between the United States and the Soviet Union.

World War II was the deadliest war in human history. As many as 75 million people were killed during the war.

## The Prelude to War

The lead up to World War II began almost immediately after World War 1 ended with Germany humiliated and forced to pay reparations. The unresolved issues from World War I, economic instability, the rise of authoritarian regimes, and aggressive expansionism for resources led to World War II. The actual beginning of hostilities is considered the point that Germany invaded Poland on September 1, 1939.

*The Treaty of Versailles (1919)*

The Treaty of Versailles ended World War I on June 28, 1919. Germany was not allowed to participate before signing the treaty. The treaty imposed severe reparations and territorial losses on Germany. Germany lost approximately thirteen percent of its territory and all overseas possessions. Germany was forbidden from annexing any other states. Germany was forced to pay reparations from the war. Critics called the reparations excessive and counterproductive. The United States never ratified the Treaty of Versailles.

Another limit placed on Germany by the Treaty was on the size and capabilities of its military. This disarmament left a lot of resentment that was later exploited by Adolf Hitler in his rise to power.

*Rise of the Totalitarian Regimes*

In Germany, Adolf Hitler and the Nazi Party were elected in 1933. They promoted nationalism, anti-Semitism, and reversing the Treaty of Versailles.

In Italy, a fascist regime was established by Benito Mussolini in the 1920s. He pursued imperial ambitions, such as Ethiopia in 1935.

A militaristic regime gained power in Japan in the 1930s. They promoted expansion into Asia and took over Manchuria in 1931 and China in 1937.

*Global Economic Depression (1929-1939)*

The Great Depression led to unstable economies throughout the world. This instability led to support for radical political movements. Democratic societies tend to work slower and less decisive.

*Failure of the League of Nations*

The League of Nations was ineffective. It did not curb the aggression of fascist states. It failed to act decisively during the Japanese invasion of Manchuria in 1931. It did not act during the Italian invasion of Ethiopia in 1935. It also did little to stop the German rearmament and expansion of its territory.

*German Aggression and Appeasement*

Germany began remilitarization of the Rhineland in 1936 in violation of the Treaty of Versailles. In 1938, Germany annexed Austria and the Sudetenland (in Czechoslovakia) after the Munich Agreement, which was an act of appeasement by Britain and France. Germany occupied the remainder of Czechoslovakia in March 1939.

*Nazi-Soviet Pact (Molotov-Ribbentrop Pact, August 1939)*

A non-aggression treaty was made between Germany and the Soviet Union. There was also a secret plan to divide Eastern Europe between them under the Molotov-Ribbentrop Pact.

*Invasion of Poland (September 1, 1939)*

The war officially began on September 3, 1939, after Germany invaded Poland on the first of September. They had staged several false flag border incidents to justify the invasion. They used blitzkrieg tactics. Britain and France had pledged to defend Poland, thus declared war on Germany. The Soviet Union invaded Poland from the East on September 17, 1939, in accordance with the Nazi-Soviet Pact.

*Battle of the Atlantic (1939 to 1945)*

The Battle of the Atlantic was a struggle between German U-boats and Allied convoys. This was based on keeping Britain and Allied troops supplied. The Allies were helped by advances in sonar, radar, depth charges, codebreaking (Ultra), and the use of escort carriers.

Sonar (Sound Navigation and Ranging) was decisive during the Battle of the Atlantic. It began with the British Anti-Submarine Detection Investigation Committee (ASDIC) technology, which was an early form of active sonar. This allowed detection of German submarines.

Also used in the Atlantic was a technique called degaussing to combat magnetic mines. This was first used on British naval vessels in 1939 and 1940.

*The War in Europe Expands (1939-1940)*

Poland was defeated and partitioned by Early October 1939. From the Fall of 1939 to the Spring of 1940 there was a period of relative inactivity on the Western Front. Britain and France mobilized but avoided offensive action against Germany. This eight-month period of relative inactivity was called Sitzkrieg or “Phoney War”.

*Blitzkrieg and the Fall of Western Europe (1940)*

The inactivity did not last very long. In April 1940, Germany invaded Denmark and Norway. They were trying to protect shipments of iron ore from Sweden that the allies were attempting to cut off. Both countries fell quickly with Denmark taking 6 hours and 2 months for Norway. On May 10, 1940, British Prime Minister Neville Chamberlain was replaced by Winston Churchill

and Germany launched an invasion of France. The invasion used a flanking maneuver through neutral nations to avoid the Maginot Line. They also used Blitzkrieg tactics they had developed. France surrendered on June 22, 1940. A German puppet regime was set up in southern France, known as Vichy Government.

In late May to early June 1940 British and Allied troops were evacuated across the English Channel from Dunkirk.

*The Battle of Britain (July to October 1940)*

Fought entirely by air forces. Germany began aerial bombardment of Britain to prepare for a land invasion. Operation Sea Lion was the German plan for the invasion of the United Kingdom. The Royal Air Force successfully resisted the Luftwaffe. Radar played a crucial role in the detection and interception of Luftwaffe aircraft. The planned invasion of Great Britain was eventually abandoned.

*Axis Powers (1940)*

In September 1940, Germany, Italy, and Japan signed the Tripartite Pact. This pact formed the Axis Powers. Italy invaded Greece from Albania. They faced setbacks in the invasion.

*A Global War (1941)*

Germany assists Italy, invading Yugoslavia and Greece. On June 22, 1941, the Germans began Operation Barbarossa where Hitler betrayed Stalin and invaded the Soviet Union, which opened the Eastern Front. This was the largest land invasion in history. The Germans made swift advances but were eventually slowed down by a combination of the resistance and the winter.

The Atlantic Charter was made on August 14, 1941. Franklin D. Roosevelt and Winston Churchill had a secret meeting off the coast of Newfoundland. They issued the Atlantic Charter, that outlined the shared goals for a postwar world. These goals were self-determination, free trade, and disarmament.

## The United States Entry into the War

In 1939, the United States was officially neutral but gradually supported the Allies. An arms policy called Cash-and-Carry in 1939 was a policy where the US sold arms to the Allies if they paid cash and transported the arms themselves. The end of official neutrality came in 1941 with the Lend-Lease Act (March 11, 1941). During the war, bazookas were provided by Lend-Lease to Britain, Canada, China, the Soviet Union, and Free French forces.

Japan was at war with China in 1941. The United States placed embargoes on oil and resources, which threatened Japan. On December 7, 1941, the Japanese Empire launched a surprise attack on the Pacific Fleet at Pearl Harbor, Hawaii. Figure 1 shows a Japanese plane during the attack on Pearl Harbor. There were many clues to the coming attack that were missed by the United States military. There were over 2,400 Americans killed (almost half on the USS Arizona). Figure 2 shows the wreckage of the USS Arizona. Numerous ships were damaged or destroyed, including the USS Arizona. One bit of technology the Japanese used was wooden fins on their torpedoes. They broke away and prevented torpedoes from going too deep before leveling off. Pearl Harbor was too shallow for most torpedoes, so they were attempting to repeat what the British accomplished at Taranto.

The attack on Pearl Harbor though was not the knockout blow that the Japanese had hoped. The three American carriers were a primary target and they were not at Pearl Harbor when the attack occurred. Furthermore, the Japanese did not hit the fuel and oil supplies at Pearl Harbor. The repair facilities were not targeted either.

The biggest mistake the Japanese made would cost them dearly in the long run. Many Americans were isolationist after World War I. The Japanese declaration of war on the United States did not reach American authorities until after the attack had started, which infuriated even these Americans that were isolationist. It was not blow to American morale, but a rallying point.

Figure 1. Japanese planes attack Pearl Harbor. (Library of Congress)

Figure 2. The wreckage of the USS Arizona. (Library of Congress).

The day after Pearl Harbor, the United States Congress declared war on the Empire of Japan. On December 11, 1941, Germany and Italy declared war on the United States (due to Tripartite Pact). The US responded in kind, thus entering the war in Europe and the Pacific.

A few hours after the attack on Pearl Harbor, the Japanese targeted American aircraft at Clark Field in the Philippines and British airpower at Hong Kong.

The Japanese conquered much of the Western Pacific until 1942, when its advances were halted. This was after they were defeated in the naval Battle of Midway.

*Doolittle Raid*

The Doolittle Raid was an attack on Tokyo occurring on April 18, 1942. It was an initial retaliation for the Japanese attack on Pearl Harbor. It was accomplished by having B-25 bombers take off from an aircraft carrier. It was considered a success, even though it caused only minor damage. It demonstrated to the Japanese people that we could reach their capital city, so it was a morale boost for the United States.

*Siege of Leningrad (September 1941 to January 1944)*

The city of Leningrad was blockaded for 900 days during the war. The blockade caused horrible suffering and starvation among the civilian population. The Soviets managed to hold the city until the siege was broken.

*Battle of Moscow (October 1941 to January 1942)*

Hitler had planned to take Moscow before the Winter of 1941 in Operation Typhoon. The Battle of Moscow occurred on the Eastern Front from October 1941 to January 1942. The German Army came within 15 to 20 miles from the outskirts of Moscow. The Soviets held off the Germans, due to the freezing weather. The Germans had difficulties getting supplies through to their troops. The Soviets brought in troops from their Far Eastern and Siberian Military Districts to help defend the city, as they built three defensive belts. The Harsh Russian Winter halted the German Army, and it was the first major German defeat on land.

*Battle of the Coral Sea (May 1942)*

This was the first naval battle that was fought entirely by carrier-based aircraft. The US and Japanese fleets were never in sight of each other. The Japanese advance towards Australia was halted. This set the stage for the Battle of Midway.

*Battle of Midway (June 1942)*

The Battle of Midway was a naval battle where the US had learned of the Japanese plans to attack. Codebreakers had learned of Japanese attack plans, so US aircraft carriers had ambushed the Japanese fleet, and sank four aircraft carriers. The Battle of Midway shifted the balance of power in the Pacific and put the Japanese on the defensive.

*Battle of Guadalcanal (August 1942 to February 1943)*

The Battle of Guadalcanal was the first major Allied offensive in the Pacific Theater. US Marines landed to begin several months of naval, air, and jungle (land) fighting. The Allies gained control of the Solomon Islands to attenuate the Japanese expansion.

*El Alamein (1942)*

There were two battles for this Egyptian coastal town. The first battle of El Alamein halted the German (Rommel) advance towards the Suez Canal. In the second battle, British General Montgomery, pushed Axis forces out of Egypt. This was the turning point of the North African campaign.

*Battle of Kursk (July to August 1943)*

The Battle of Kursk was a series of offensives on the Eastern Front near the city of Kursk. Kursk is 280 miles Southwest of Moscow. It was an unsuccessful attempt by Germans to overtake Soviet forces. The Germans attempted to attack Soviet forces from different directions. This helped the Soviets to reclaim the cities of Kharkov and Orel and halted the German advance. This led to the largest armored battles on July 12, 1943, the Battle of Prokhorovka.

*Battle of Stalingrad (August 1942 to February 1943)*

The Battle of Stalingrad was one of the bloodiest battles in history. The German forces fought the Soviet defenders street to street. Germany's 6$^{th}$ Army was surrounded and surrendered. This was a turning point on the Eastern Front.

*D-Day (June 6, 1944)*

On June 6, 1944, the Allies invaded German-occupied France at Normandy. The Allied amphibious landings at Normandy were codenamed Operation Overlord. At the same time the Soviet Union regained its territorial losses, while pushing Germany westward. The successful landings at Normandy led to the defeat of the German Army units in France. Paris was liberated on August 25, 1944.

*Battle of Leyte Gulf (October 1944)*

This was the largest naval battle in history. It was also the first large usage of kamikaze attacks by the Japanese. US forces cut off the Japanese from resources under General Macarthur and Admiral Nimitz.

*Battle of the Bulge (December 1944 to January 1945)*

This was Germany's last major offensive in the West. It was launched through the Ardennes to split the Allied lines. The name comes from the bulge in the front line. The element of surprise and the winter weather favored Germany initially. The Allied forces regrouped and contained the Germans, exhausting the German reserves.

*Battle of Berlin (1945)*

The Battle of Berlin was the last major offensive of the War in Europe. The Soviets had temporarily halted after the Vistula-Oder Offensive of January to February 1945. At that point, they were 60 kilometers east of Berlin. The Soviets attacked the city of Berlin in April of 1945. They attacked the city from the south and the east. The Soviet Army surrounded the city by April 20, 1945. The 1st Belorussian Front began shelling the city as the Ukrainian Front entered the city's southern suburbs. Before this battle was over, Hitler and many of his followers had committed suicide. The city was divided into four sectors after the war ended.

*Battle of Iwo Jima (1945)*

This was a Pacific island battle where the US Marines encountered fierce Japanese resistance in capturing the island. The island provided an air base for US bombers. The raising of the flag by US Marines on Mount Suribachi became an iconic symbol of the battle, although it was a recreation.

*Battle of Okinawa (April to June 1945)*

This was the final major battle of the Pacific war. The Japanese put up a fierce resistance and used kamikaze attacks, inflicting heavy US casualties. This was a staging ground for the possible invasion of Japan.

## Engineering and Scientific Developments

The British conducted very little military research and development just after World War I. This is due to the Ten Year Rule beginning in 1919, (abandoned March 23, 1932) where the government should not expect another war within 10 years. Russia and Weimar Germany, however, cooperated with each other building and testing weapons deep inside the Soviet Union. Artillery manufacturer Krupp located a facility in the Soviet Union near Rostov-on-Don.

In 1925, the Lipetsk fighter pilot school was established to train future Luftwaffe pilots. The Reichswehr (German armed forces) used the Kama tank school in Kazan since 1926. They also tested chemical weapons at the Tomka gas test site located in Saratov Oblast.

Germany helped Soviet industry to modernize in the late 1920s. They assisted in the establishment of tank production facilities. The cooperation between the Soviets and Germany broke down when Hitler rose to power in 1933. The failure of the World Disarmament Conference in 1934 marked the beginning of an arms race.

France built the Maginot Line that was supposed to protect the border with Germany. It did assure that an invasion of France had to go through Belgium and that France would have Britain as an ally. At the beginning of hostilities France and the Soviet Union had better tanks than Germany, but outdated tactics against the German blitzkrieg.

By 1940, National Bureau of Standards (NBS, now NIST) had a lot of confidential projects and a fence was built around the NBS grounds. By 1943, the entire NBS staff was engaged in work for the war effort. They did various activities for the war to include calibrating gage blocks, making effective coating for munitions, testing quartz crystals for radio equipment, developing new metal alloys, designing carbon monoxide indicators for fighter planes, and testing new plastics and textiles.

### *Nuclear Technology*

There were numerous scientific and technological advancements during the war, but none received as much attention as the atomic bomb. In 1938-1939, induced nuclear fission was discovered in Germany by Otto Hahn, Fritz Strassmann, and Jews in Germany before they moved to Sweden. They split uranium nuclei by bombarding uranium with slow neutrons. The theoretical explanation led by Lise Meitner and Otto Frisch showed the development of an atomic bomb as a possibility. It was alarming to refugees that the German atomic bomb project could build one.

Germany began nuclear reactor research in 1940. They were using heavy water as a moderator, since they considered graphite too ineffective due to impurities. Germany had secured a steady supply of heavy water after the German Army captured the production facilities of the Norwegian Hydroelectric Company in April 1940. There were a series of sabotage efforts between 1942-1943 by the Norwegian Resistance and Allied bombing. The German research

effort had fizzled out by the end of June 1942. Hitler had labeled the research effort as "Jewish physics" and refused to provide any additional support.

Frisch and Rudolf Peierls worked under Mark Oliphant at the University of Birmingham and made a breakthrough in the study of the critical mass of uranium 235 in June 1939. They calculated that it was within an order of magnitude of 22 lbs., which was small enough to be carried by the bombers available at the time. The MAUD Committee was established as well as the directorate known as Tube Alloys to pursue atomic weapons. The British Tube Alloys nuclear weapons research project was eventually absorbed into the Manhattan Project.

Much of the initial basic American research was conducted by NBS that was eventually transferred to the Manhattan Project. It demonstrated the importance of having a centralized direction for development. Participants in the Manhattan Project have commented that the United States would never have built the atomic bomb in peacetime. The American Project was under the direction of Brig Gen Leslie R. Groves of the United States Army Corps of Engineers (USACE). The Army component was labeled "Manhattan District" because the first headquarters was in Manhattan. The Manhattan Project began in 1942. The British and American projects were merged with the Quebec Agreement in August 1943, and a British mission joined the Manhattan Project in the US. At its peak, over 500,000 people worked on the project at one time or another and it built three secret cities.

Ninety percent of the cost of the Manhattan Project was for building factories and producing fissile material. The fissile isotope Uranium-235 is only 0.7 percent of natural uranium. Uranium-238 and uranium-235 are chemically identical, but radiologically different. At the same time, they were enriching uranium at the Clinton Engineer Works in Oak Ridge, Tennessee. They were trying to produce plutonium in Hanford, Washington.

The weapon design was under Project Y at Los Alamos, under Robert Oppenheimer. The Manhattan Project pursued two types of bombs, one a gun-type fission weapon using enriched uranium (Little Boy) and the other an implosion type weapon using plutonium (Fat Man). Variations of these were used against Hiroshima and Nagasaki respectively, in August 1945.

A successful test was conducted, known as the Trinity Test, occurred on July 16, 1945 in the desert of New Mexico before the dropping of the bombs on Japan. Figure 5 shows the mushroom cloud that formed after the bomb was dropped on Hiroshima on August 6, 1945. The Germans and Japanese both had nuclear programs that failed for lack of interest and resources. Figure 3 shows the target area of the Hiroshima bomb before the dropping of the bomb. The aiming point was the T-shaped bridge to the left of center in the figure. Figure 4 shows the same area after the bombing. The destruction is quite apparent in the photo.

Figure 3. The target area of the Hiroshima bomb before. (Library of Congress)


Figure 4. The target area of the Hiroshima bomb after. (Library of Congress)

Figure 5. The Hiroshima mushroom cloud. (Library of Congress)

The bombs dropped on Japan and the Soviet Union's declaration of war in August 1945 led to Japan's surrender and ended World War II. The two bombs killed over 200,000 people. The world's political landscape changed after the war as the Soviets developed their own bomb. Mutually Assured Destruction became the only deterrence.

The history of atomic research in the United States demonstrated the importance of a centralized direction for the technological development of the bomb. The Manhattan Project provided that direction. Japan lacked a centralized office for the coordination of its atomic research.

*Code Breaking (Cryptography)*

Cryptography became important in World War II. They had developed ciphers before the war that were mostly rotor machines. The Germans had broken most of the British and American military ciphers by the end of 1940, with the exception of the Enigma-based Typex.

The Germans used a variation of the Enigma coding machine (operations communications) and Lorenz cipher (strategic messages) for coding communications. The British developed a method of decoding Enigma from information given to them from the Polish Cipher Bureau. They later

accomplished a cryptoanalysis of the Lorenz cipher. Code breakers based at Britain's Bletchley Park (which looked like an old run-down mansion) played a vital role in the defeat of Germany.

One of the more famous cryptoanalysis projects was Operation Magic that involved the US Army's Signals Intelligence Service and The US Navy's Communication Special Unit. This moved the government's cryptologic capabilities under one agency that was dubbed the Research Bureau.

Breaking Japanese codes had several important successes. One of these happened in 1923, where a US Navy offices acquired a stolen copy of the Secret Operating Code codebook used by the Imperial Japanese Navy during World War 1. Photographs were taken and given to cryptanalysts, and the processed code was called "Red" to indicate its Top Secret classification.

In 1930, the Japanese government created another, more complex code that was codenamed "Blue". It was broken by the Research Desk by 1932.

Germany began sending technical assistance to Japan after the war began in the fall of 1939. Part of this assistance was sending Japan modified Enigma machines. The new code was dubbed "Purple". Codebreakers could not break the code manually. Some of the "Purple" code was decrypted by a reversed engineered machine in 1939. They did this by replicating some of the settings of the Japanese Enigma machines.

The Japanese Foreign Office used a cipher machine to encrypt its diplomatic messages. The machine was called "Purple" by the US cryptographers. It worked by typing a message into a machine, which enciphered and sent it to an identical machine. The receiving machine could only decipher the message if the correct setting were set. The American cryptographers built a machine that could decipher these messages.

The "Purple" machine was first used by Japan in 1940 and carried diplomatic traffic to its embassies from the Foreign Office. Some "Purple" traffic was broken by US and British cryptographers long before the attack on Pearl Harbor. The Foreign Office deliberately withheld a lot from its embassies and consulates, so it was difficult to understand military intentions.

Just before Pearl Harbor, the 14-part message breaking off negotiations had been decoded and translated before the Japanese Embassy could do so. They had trouble so the attack occurred before the Japanese Embassy finished decoding and translating.

*Radar*

Radar technology was developed before the war. The forerunner of radar (radio detecting and ranging) was developed in 1904 when German physicist Christian Hulsmeyer developed a device to transmit radio waves and receive their reflection off objects to detect the range, angle or velocity of objects. It was the ability to use radio waves to detect objects at a distance through the measurement of the time it takes for the waves to travel to an object, be deflected, and return.

The first practical radar system was produced by the British physicist Sir Robert Watson-Watt in 1935. By December of 1938 there were 5 radar stations off the coast of Britain and construction had begun on fifteen others. By the year 1939 England had built a radar network along its south

and east coasts, known as Chain Home. The ability to detect hostile planes and ships at a distance gave a significant advantage. It also reduced the element of surprise.

In 1939, the Aircraft Warning Service (AWS) was established for the defense of American Territories. This included Hawaii.

In the early 1930s, radar research was being conducted in the United States, Britain, Germany, and Japan. Development was different in all of the countries. In terms of the technology, the Germans were ahead but fell behind after the war started. The Germans were hampered by bureaucratic agencies that did not communicate well among themselves. The British were better at the operational development of radar by the time the war began. Radar allowed forces to detect incoming aircraft before they were visible. The British effort benefited from the direction and funding from the Tizard Committee before the war.

The United States lagged in radar research due to lack of a central agency to focus the research effort. Japan lacked a centralized effort to address technical problems with radar.The United States did not show much interest in radar until 1939. Radar operators at Opana, on the island of Oahu, spotted the Japanese as they were moving to attack Pearl Harbor, but it was confused with some B-17s coming in from the US mainland. This was the first operational use of radar in wartime by the United States and one of the missed clues of the attack. Figure 6 shows the plot from Opana.

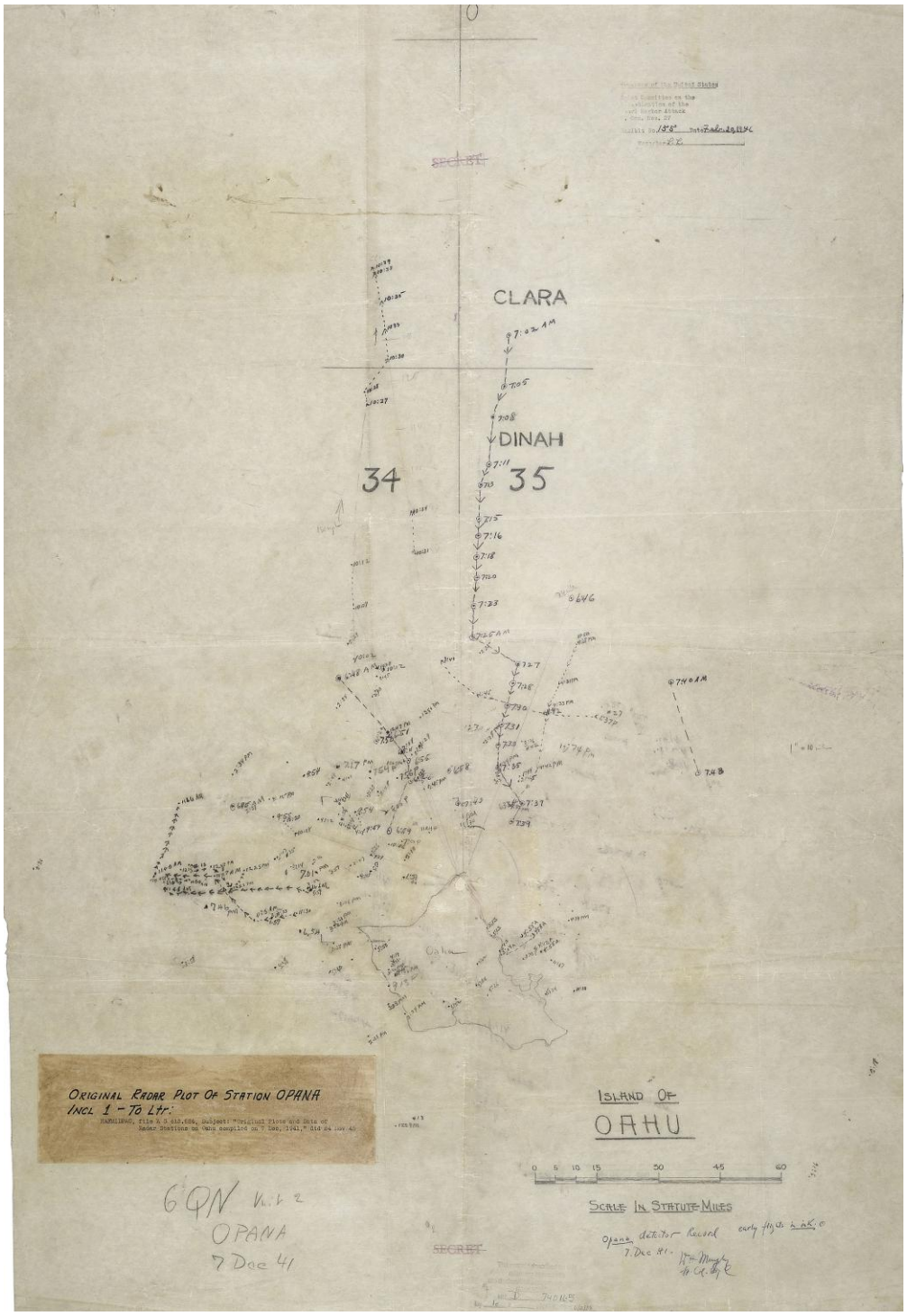


Figure 6. The plot from Opana from the day of the attack on Pearl Harbor. (Library of Congress)

The detection of Japanese aircraft was important during the Battle of Midway in 1942. Radar gave the United States a technological advantage during the war in the Pacific in 1942. Radar was further developed and widely deployed during the war. The British network gave them a vital early warning of approaching German Luftwaffe aircraft in 1940 during the Battle of Britain which reduced the effectiveness of the Luftwaffe bombing raids. Radar allowed the British to efficiently deploy their fighter interceptors against the German bombers. For the US, radar was important in the Battle of Midway in June 1942, being used to detect Japanese planes. Radar was also used at sea to detect ships and submarines.

Radar became essential in meteorology after the war. This too developed during the war. They tracked storms, like before D-Day in 1944, which became critical for military operations. Today, radar technology is used in weather forecasting and air traffic control

Not only was radar developed, but countermeasures to attempt to defeat radar. Allied bombers dropped tiny strips of tinfoil to jam enemy radar. The British used small strips of aluminum foil to create a blur of echoes. This was known as Window.

*Computers*

The word "computer" has evolved since the beginning of World War II. In the early 1940s "computers" were mostly women who performed complex hand calculations. During the war machines were developed and hand calculations shifted to programming these new machines.

Then the British developed an electro-mechanical machine known as the Bombe. It helped to break the German Enigma cipher. It was a parallel development to the Colossus machines.

The British also developed the first programmable, electronic, and digital computer during World War II. The Colossus computer had the single purpose of helping to break the complex German Lorenz ciphers. Human codebreakers would have taken weeks to do what the computer did in a few hours.

A computer that was designed for military purposes was not completed until 1945. It was the Electronic Numerical Integrator and Computer, known as ENIAC, at the University of Pennsylvania. It was a general purpose computer that could perform thousands of calculations in a second. It was released to the general public in early 1946. It occupied up to 1,500 square feet and cost $400K, so it was not for the average consumer, due to size and cost.

*Jet Engines*

The first patent for the jet engine was filed by Frank Whittle, a British Engineer with the Royal Air Force. When the war began, all aircraft were propeller driven. The jet engine propelled an aircraft by expelling exhaust at a high speed. The development led to faster and higher flying aircraft.

The first country to use a jet engine in flight was Germany, being developed by Hans von Ohain. That was August 27, 1939, just a few days before Germany invaded Poland. The first allied jet propulsion was on May 15, 1941. Germany and Britain had both developed jet aircraft by 1944.

The first operational jet aircraft was the German Me 262 fighters, which first flew in 1942, but did not enter service until 1944. It saw combat service in 1944 during the Battle of the Bulge.

These early jets paved the way for development after the war, but effectiveness was limited during the war. Its impact on the war was limited due to production delays and fuel shortages. The use of jets led to them becoming the standard in air forces throughout the world.

After the war, jets developed fast and went faster and higher. In 1947, the Bell X-1 broke the sound barrier with Chuck Yeager as the pilot.

*Rockets and Ballistic Missiles*

Rocket technology was developed at an accelerated rate during World War II. Rockets had already existed. The German V-2 (Vengeance Weapon 2 or Vergeltungswaffe 2) was the first long range guided ballistic missile and was probably one of the most significant technologies developed during the war. The first successful test flight of the V-2, developed by Wernher von Braun, was conducted on October 3, 1942. There were over 3,000 launched during the war. The main target was London, but later Belgium and France in 1944 and 1945. It terrorized civilian populations.

V-2 technology was used after the war to develop postwar missiles for the Cold War and rockets for the Space Race after von Braun was brought to the United States. The Redstone rocket was directly influenced by the V-2.

*Microwave Ovens*

The microwave oven had origins in World War II. It was a cavity magnetron, used in radar technology, that generated microwaves during the war. It was research into radar that led to the discovery by engineer Percy Spencer. In 1945, he noticed that a candy bar in his pocket melted when he was working on an active radar set. He began experimenting with other foods, such as popcorn, giving the basic idea for the microwave. It took a time after the war to develop the idea.

*Proximity Fuse*

The radio proximity fuse was designed by the National Bureau of Standards. This technology was first tested in 1941. The "radio proximity fuse" was a tiny radio transmitter and receiver about the size of a light bulb. It is a fuse that automatically sets off an explosive when it comes within a predetermined distance of a target. It was a tiny radar set put into an artillery shell. These new fuses were designed to trigger the explosion when they neared their target. Variations were designed for rockets, shells, and bombs. It was used to help protect London from the V-1. The first major combat use was during the pre-invasion bombardment of Iwo Jima in 1945. They were also used against kamikaze attacks.

By the end of the war proximity fuses had become a critical component of many anti-aircraft artillery shells. They were widely used in anti-aircraft defense in the Battle of the Bulge in 1944 through 1945.

*Guided Missile*

The Bat was the first fully automated guided missile. NBS worked on the aerodynamic and stabilization characteristics of the missile. It emitted shortwave radiation and was guided by radar echoes of the target. The Bat was known for its long range, high accuracy, and high payload. The Bat was used in the Pacific Theater against Japanese shipping targets.

*Guided Bomb*

Designed to hit moving ships. One of the first guided munitions developed by Germany, known as the Fritz X. The Fritz X sank the Italian battleship Roma on September 9, 1943, off the coast of Sardinia. They had versions that were radio controlled and wire guided.

*Synthetic Materials*

Wallace Carothers, an organic chemist, invented Nylon in 1935 with his team from DuPont. It was used to manufacture military gear when natural materials were scarce.

Natural rubber from the Far East was cut off during the war. Gasoline in the US was rationed to discourage driving, due to rubber tires on cars. The National Bureau of Standards set up a lab to test rubbers from South America, Central America, and Africa. A consortium was organized to study synthetic rubbers and build production plants. In 1943, NBS began to standardize physical and chemical testing of rubbers. President Roosevelt's administration invested $700 million in 51 plants that produced synthetic rubber from petroleum by-products. These became essential for tires, seals, and other applications in military equipment and vehicles. By 1944, synthetic rubber plants produced 800,000 tons of material annually.

Synthetic fuel was also developed during the war. New high-octane fuels were developed to fight shortages of oil. Germany experienced fuel shortages, so chemist Hermann Zorn and others developed fuels and lubricants from coal or other materials.

*Napalm*

Napalm was first used in World War II. Although we may associate it with the Vietnam War, it was a product of World War II. It was first used in flamethrowers in 1943 during the invasion of Sicily. Incendiary bombs were later developed using napalm as a replacement for thermite.

*Duct Tape*

Duct tape was developed during the war by out of a need for a strong and waterproof tape for sealing ammunition cases. It was developed by Johnson & Johnson in 1942. It was originally called "duck tape" because it was water resistant. Its durability and versatility made it indispensable for military repairs. After the war it became known as "duct tape" because it was useful in sealing ventilation ducts.

*Superglue*

Superglue was discovered by accident by American scientists trying to create clear plastic gunsights at Eastman Kodak. Their formula, known as cyanoacrylate, was too sticky for the

original purpose in military optics. It was later marketed as a strong glue. It was used later as a fast way of sealing wounds later during battle in the Vietnam War.

*Aerosol Spray*

Another development during World War II was aerosol spray soldiers in the Pacific Theater needed a portable method to spray for malaria carrying pests. The first aerosol spray cans were tested as early as 1862, but were too bulky to be practical. The first patent for an aerosol can with a valve to dispense was in 1927 by Norwegian engineer Erik Rotheim.

Aerosol spray with fluorocarbon was developed in 1943.

*Ballpoint Pens*

The ballpoint pen was another invention that existed before the wat, but was unreliable. Laszlo Biro improved the design in the 1930s. He used fast-drying ink that worked well at high altitudes, which made it ideal for pilots. The British Royal Air Force adopted these for their flight crews during the war. After the war, they became popular with the public.

*Military Vehicles*

One development that was designed and mass produced a few months after the war began was the Jeep. The US Army had a need for a lightweight, all-terrain vehicle for reconnaissance. It set out in 1940 on this endeavor in case we were drawn into war. The Army called upon American automakers to submit designs for a "general purpose" military vehicle that weighed no more than 1,300 pounds and could climb a 45-degree slope fully loaded and could make it through water up to 18 inches deep.

Three car companies were awarded production contracts. The vehicle received the nickname "jeep". It was a quite adaptable vehicle and could be used in many different ways. It was the forerunner of the SUVs that we have today. The Jeep was used in every campaign since 1941. They were especially used in North Africa, Normandy in D-Day, Italy, and the Pacific. It became ideal for reconnaissance and transport due to its versatility in rough terrain.

Another military vehicle was known as the "Duck". Officially it was the DUKW and was an amphibious vehicle, capable of operating on land and water. It was used for moving supplies and troops in amphibious landings.

*Helicopters*

The Flettner Fl 282 Kolibri was the first production helicopter used during the war. The helicopter is a rotary wing aircraft designed to make vertical takeoff and landing. It could hover, making it ideal for reconnaissance. It was used for reconnaissance in the Mediterranean and the Eastern Front (1944-1945).

Its intended roles were for reconnaissance and ferrying items between ships for the German Navy. At the end of the war, some of these helicopters were captured by American and by Soviet forces.

The Flettner Fl had a maximum speed of 93 miles per hour and had a range of 110 miles. It had a crew of 1, but later versions allowed for an observer. The Luftwaffe had adapted the aircraft for use on the battlefield for spotting artillery.

The first helicopter to be mass-produced was the Sikorsky R-4. It was first flown in 1942 and was used in combat in 1944 for the first time. It was used for search and rescue operations in the Pacific Theater. Military helicopter use accelerated during the Korean Conflict and entire Cavalry Units used them during the Vietnam War.

Today helicopters are still used for search and rescue, medical transport, law enforcement, and military missions.

*Tanks and Armored Vehicles*

Tanks had existed before the war. There were developments in tank design that were significant. The German Tiger I tank came out in 1942. It had an 88 mm gun and its armor was 100 mm thick. The Tiger I could engage targets at a distance with great accuracy. The Tiger I forced the Allies to work on development of tanks. It was used in Leningrad in 1942 and Kursk in 1943.

The Soviets came out with the T-34 which had sloped armor and a 76.2 mm gun. It had mobility and was used in the Soviet counterattack on the Eastern Front. There were 57,000 T-34s manufactured during the war. It had a simple design that allowed for easier production. They were used in the Battle of Moscow in 1941. They proved their effectiveness in the Battle of Kursk in 1943. They had a significant role on stopping the German advance.

The American M4 Sherman tank was a reliable tank that could be produced in large numbers. It was not as heavily armored as the Tiger I. There had been 49,000 of these built by the end of the war. They outmaneuvered the German tanks in North Africa and in Western Europe. They outnumbered the German tanks, allowing them to overwhelm them with mass numbers. There was heavy usage of the M4 Sherman tank in North Africa in 1942 to 1943. They were used in Normandy on D-Day and across the European Theater.

*Cruise Missile*

The Germans developed the V-1 flying bomb in 1939. They were known to the Allies as Buzz Bombs. It was the first of the V-weapons (Vengeance weapons) that were used against London in 1944. A total of 9,521 were launched beginning on June 13, 1944, in response to Operation Overlord. The last V-1 site directed at England was overrun in October 1944. After this, they directed most at targets in Antwerp and other targets in Belgium for a total of 2,448 in 1944 and 1945. This lasted until just before the end of the war. Finnish soldiers observed tests of the V-1 being dropped from a plane in 1944 and thus dubbed them “flying torpedoes”.

*Bazooka*

The bazooka was a portable recoilless rocket launcher that gave infantry units an effective way to counter armored vehicles. It was used as an anti-tank weapon by the United States Army. It was influenced by Robert H. Goddard (Father of Modern Rocketry) as a side project during World War I. Development was discontinued with the end of the war. The project was picked

back up as a project with the goal of stopping German tanks during World War II. Col. Skinner and Lt. Uhl took on the project. It was eventually demonstrated to General George C. Marshall. Figure 7 shows a soldier demonstrating a bazooka.

Figure 7. Soldier with a bazooka. (Library of Congress)

A shipment of 600 bazookas was shipped to the British Army in Egypt in 1942. They were not used in that terrain due to the lack of concealment in the desert.

The bazooka was deployed during Operation Torch from November 8, 1942 to November 16, 1942. They were hastily deployed, without any instruction in usage of the weapon. Further issuance of the bazooka was suspended after General Eisenhower visited the Tunisian front and could not find a soldier reporting it stopping an enemy tank.

A number of the early production bazookas were captured from the Red Army by the Germans in late 1942. The Germans reverse engineered and developed their own version of the weapon, called the Panzerschreck.

General George S. Patton wrote to a colleague on May 20, 1944. He stated that the bazooka was not to hunt tanks offensively but used as a last resort to keep tanks from overrunning infantry.

He advised keeping the range at a maximum of 30 yards. The American tank expert, General George S. Patton is shown in Figure 8.

Figure 8. George S. Patton, American tank expert. (Library of Congress)

In the Pacific Theater, the bazooka became effective against small concrete bunkers, pillboxes, and fixed Japanese infantry emplacements.

*Pressurized Cabin*

The pressurized cabin was developed during World War II. Pressurizing a compartment protects the crew and passengers from hypoxia, which is a lack of oxygen at high altitude. Air is pumped into the cabin to mimic sea level conditions.

The first airliner with pressurization cabin was the Boeing 307 Stratoliner, produced in 1938. The planes initially used during the war relied on oxygen masks. The need for pressurization came with the larger bombers that required the crew to move around and cabin. The B-29 was the first bomber with a pressurized cabin and crew compartment.

Pressurized cabins allowed planes to fly above weather and turbulence which became widely used in commercial aircraft after the war.

*Mobile Radios*

Mobile radios were developed during World Ward II and were the forerunners of our cell phones. The first portable two-way radios were developed by Canadian engineer Donald Hings

and American company Motorola. They allowed soldiers to communicate over long distances without wires.

*Frequency Hopping*

A method to prevent enemies from jamming radio signals was developed in 1941. It was developed by actress Hedy Lamarr and composer George Anthell. The idea was to have the signal change channels in sync between the sender and the receiver. It was patented in 1941. It formed the basis for modern wireless technology.

*Operations Research*

Operations Research emerged as a formal discipline in World War II. It is usually associated with Industrial Engineering. It brought together many disciplines to apply scientific methods, statistics, probability, and mathematical analysis to operational military problems. The goal was to use resources efficiently, much like Industrial Engineering is used in manufacturing today.

The type of problems created by the situations in World War II had uncertainty, limited resources, and time limitations. These were the type of constraints that Operations Research was designed to deal with. Operations Research gave a quantitative analysis to help in the decision making. Before the war, military decisions were based on doctrine and experience. After the war, military decisions were made by data, models, and probability. It was the addition of several issues that drove the change. These included large scale naval and air operations, the addition of new technologies (i.e. aircraft, radar, sonar, and submarines), limited resources used in different theaters, and high costs in casualties and materials for bad decisions.

Table 1 shows the problems that Operations Research was used for during the war.

**Table 1. Operations Research: Problem → Analysis → Decision → Result**

| Operational Problem | OR Analysis Used | Decision Made | Result |
|---|---|---|---|
| Convoys being sunk too frequently | Probability modeling of convoy size vs. loss rate | Increase convoy size | Fewer losses per ship sailed |
| Aircraft vulnerable to enemy fire | Statistical analysis of returning aircraft damage | Reinforce undamaged areas | Increased aircraft survivability |
| Ineffective depth charge attacks | Pattern dispersion modeling | Change depth charge spacing and depth | Higher U-boat kill rates |
| Fighter aircraft arriving too late | Radar data timing analysis | Earlier scramble orders | Increased interception success |
| Poor AA effectiveness | Probability of kill (Pk) modeling | Adopt proximity fuses | Major increase in aircraft destroyed |
| Excess fuel consumption in air missions | Mission profile optimization | Change cruising altitude and power settings | Extended range and sortie rates |
| Logistical bottlenecks after landings | Throughput and queue modeling | Reallocate port and transport assets | Sustained operational momentum |
| Excessive bomber losses | Formation and altitude modeling | Adjust formations and bombing altitudes | Reduced attrition |
| Island assault casualties too high | Bombardment effectiveness modeling | Extend pre-landing bombardment | Reduced infantry casualties |
| Limited naval forces vs. enemy fleet | Intelligence probability analysis | Concentrate forces at decisive point | Strategic victory (Midway) |

Operations Research was used in several areas during the war. It was used in the Battle of the Atlantic in anti-submarine warfare. Allied shipping was being sunk by German U-Boats at a high rate. Operations Research made contributions to help minimize the issue in a couple of ways. First, it helped determine the optimal convoy sizes, showing that larger convoys were safer than smaller ones and helped determine the number of escort ships needed. Operations research was also used to analyze depth charge patterns and air patrol routes. One fact that was proven is that aircraft patrols should be near ports, and not in the middle of the ocean.

Operations Research was also used during the Battle of Britain. There was a limited number of fighter aircraft and modeling was conducted to determine a way to efficiently intercept the German bombers. Operations Research helped determine the best spacing for radar stations. It also helped determine the best timing for scrambling the fighter planes. Formation and altitude data was analyzed and command decisions were improved. Operations Research thus allowed the Royal Air Force to maximize the use of limited resources to defeat the Luftwaffe.

Aircraft operations in general were also optimized using Operations Research. Optimal altitudes were determined. Fuel usage models were improved. Sorties rates were optimized. Crew fatigue and maintenance cycles of aircraft were analyzed.

Losses of heavy bombers became a huge problem. Statistical analysis was done on bullet hole patterns. Survivorship bias was identified and used in calculations that can lead to incorrect conclusions, based on the work of Abraham Wald. It also helped determine the locations that armor was effective. Aircraft losses were reduced.

Operations Research also helped in naval and anti-aircraft fire. It was used to analyze firing rates. It improved the use of proximity fuses. The range to engage the enemy was determined as well as the kill probabilities.

Supply and logistics were helped by Operations Research, especially when forces had to be supplied over several theaters of operations. It allowed shipping schedules to be optimized and improved the utilization of ports. Equipment bottlenecks and idle equipment were minimized. Global operations were sustained since the supply channels were optimized.

Table 2 shows the use of Operations Research by Battle during the war.

**Table 2. Operations Research by Battle / Campaign (World War II)**

| Battle / Campaign | Operational Problem | OR Methods Applied | Outcome / Impact |
|---|---|---|---|
| **Battle of the Atlantic (1939–1945)** | High Allied shipping losses from German U-boats | Convoy size optimization, probability analysis, patrol coverage modeling, depth-charge pattern analysis | Shipping losses dramatically reduced; Allies achieved convoy dominance |
| **Battle of Britain (1940)** | Limited RAF fighters vs. mass Luftwaffe raids | Radar coverage modeling, interception timing analysis, resource allocation | RAF maximized effectiveness and prevented German air superiority |
| **Strategic Bombing Campaign (1942–1945)** | Unsustainable bomber losses | Statistical damage analysis, survivorship bias correction, formation optimization | Armor added to critical areas only; bomber survivability increased |
| **North African Campaign / El Alamein (1942)** | Supply shortages and inefficient resource use | Logistics optimization, fuel and ammunition allocation models | Improved sustainment enabled Allied breakthrough |
| **Battle of Midway (1942)** | Inferior U.S. naval strength vs. Japanese carriers | Intelligence-based probability analysis, force positioning models | Decisive U.S. victory; strategic turning point in Pacific |
| **Guadalcanal Campaign (1942–1943)** | Attrition-heavy island combat and supply strain | Aircraft sortie optimization, naval engagement analysis | Sustained Allied pressure forced Japanese withdrawal |
| **Anti-Aircraft Defense (1943–1945)** | Low hit probability against fast aircraft | Firing rate optimization, proximity fuse effectiveness modeling | Dramatic increase in aircraft kill rates |
| **D-Day / Normandy (1944)** | Massive logistical and amphibious coordination | Port throughput models, landing wave scheduling, weather probability analysis | Successful landings and sustained invasion |
| **Battle of the Bulge (1944–1945)** | German surprise offensive and weather constraints | Resource reallocation modeling, artillery employment optimization | Allied lines stabilized and German offensive failed |
| **Pacific Island Campaigns (1943–1945)** | High casualties in fortified island assaults | Bombardment duration analysis, landing force optimization | Reduced casualties and faster island capture |

Operations Research in World War II transformed warfare from intuition-driven decision-making into data-driven, mathematically optimized operations — and permanently changed military, engineering, and industrial planning.

*The B-29 Superfortress*

The B-29 was the most expensive weapons project of World War II. It was named after its predecessor, the Boeing B-17 Flying Fortress, and was designed for high-altitude strategic bombing. It also excelled in low-altitude night incendiary bombing of Tokyo in 1945 and in dropping naval mines in blockading Japan. It had a pressurized cabin, dual-wheeled tricycle landing gear, and an analog computer-controlled fire-control system. The B-29 was first flown on September 21, 1942. It did not enter service until the last two years of the war.

The B-29 was planned for deployment against both Germany and Japan, but was eventually only used in the Pacific Theater against Japan. This was mainly due to production delays. It had a crew of 11, had a maximum speed of 310 knots (357 mph), and could fly as high as 31,850 feet. It had a range of 3,250 miles.

The B-29 had several features that made it unique. It had defensive gun turret emplacements. They had remotely controlled turrets. A gunner could control two or more turrets simultaneously. There was a tail gunner and a nose gunner.

The cabin and crew compartments were pressurized. The bomb compartments were not pressurized so that there would not need to be de-pressurization before opening the bomb bay doors. There was a long tunnel joining the forward and rear crew compartments to crawl from one pressurized compartment to another. Figure 9 shows a B-29 Superfortress.


Figure 9. The B-29 Superfortress. (Library of Congress)

The B-29 was used against Japan, including delivery of the atomic bombs used against Hiroshima and Nagasaki in August 1945. These were known as the Silverplate series, that was modified specifically to carry nuclear weapons.

The B-29 was very successful and copied by the Soviets to make their Tupolev Tu-4. There were several B-29s that landed in Soviet territory in emergency landings. The Soviets interned (stole) these planes to reverse engineer. After the war, the B-29 was used against North Korea and for dropping test aircraft as the space race geared up.

*Medicine*

Changes in surgery and medicine came about during World War II. Although discovered in 1928, penicillin was first developed and mass produced during the war. It was first tested in 1940 on a patient. In August 1940, it was discovered that it could be used on a variety of pathogens. This included the bacteria that caused gangrene.

It was a trio of researchers from Oxford that had published their results. They were afraid that a German invasion would force them to destroy their work so they rubbed Penicillin notatum spores into the fabric of their jackets, so they could start their research again. In July 1941, researchers Florey and Heatley sought help from the United States.

Widespread use began in 1942. It was used during the war to combat bacterial infections in wounded soldiers, especially D-Day. It saved countless lives. The process needed to mass produce it was discovered by experimentation with deep tank fermentation. By war's end, it was being mass produced by American pharmaceutical companies at the rate of 650 billion units per month. Commercial production of penicillin did not begin until after the war.

Malaria was prevented by the use of mepacrine (Atabrine). Medical advancements during the war also included sulfanilamide, blood plasma, and morphine were wartime medical advancements. Skin grafts were an advance for the treatment of burns. Tetanus was prevented by mass immunizations. The first flu vaccine was approved for military use in 1945 and civilian use in 1946.

The science of blood transfusions was perfected during World War II. The production of blood plasma for medical use was standardized by a US surgeon named Charles Drew. Unlike whole blood, plasma is not dependent on a person's blood type making it easier to use in battle.

Table 3 shows the technology used during World War II and the campaign that it was deployed.

**Table 3. Technology use in World War II.**

| Technology | Battle(s) / Campaign(s) where used |
|---|---|
| **Radar** | Battle of Britain (1940) – early warning vs. Luftwaffe; Battle of Midway (1942) – detection of Japanese planes; D-Day (1944) – weather tracking critical for invasion timing |
| **Codebreaking (Enigma, Lorenz, Magic, Purple)** | Battle of the Atlantic (1939-45) – convoy routing vs. U-boats; El Alamein (1942) – Ultra intelligence; Pearl Harbor (1941) – partial forewarning; Battle of Midway (1942) – foreknowledge of Japanese attack; D-Day (1944) – deception and planning |
| **Atomic Bomb (Manhattan Project)** | Hiroshima (Aug 6, 1945); Nagasaki (Aug 9, 1945) – led to Japanese surrender |
| **Proximity Fuse** | Battle of the Bulge (1944–45) – anti-aircraft defense; Battle of Iwo Jima (1945) – artillery bombardment; Pacific campaigns – defense against kamikaze aircraft |
| **Guided Missile (Bat)** | Pacific Theater (1945) – attacks on Japanese shipping |
| **V-1 Flying Bomb (Cruise Missile)** | London Blitz (1944) – "Buzz Bomb" attacks after D-Day; Antwerp & Belgian targets (1944–45) |
| **V-2 Rocket (Ballistic Missile)** | London (1944–45); Antwerp & other European cities (1944–45) |
| **Jet Aircraft (Me 262, first operational jet)** | Defense of the Reich (1944–45); Battle of the Bulge (1944–45) – used against Allied bombers and ground forces |
| **Bazooka** | Operation Torch (North Africa, Nov 1942) – first deployment; European Theater |

| | |
|---|---|
| | (1943–45) – used in Italy, Normandy, and beyond; Pacific Theater – effective against bunkers and pillboxes |
| **B-29 Superfortress** | Pacific Theater (1944–45) – incendiary bombing of Tokyo, mining Japanese waters, and atomic bomb missions over Hiroshima & Nagasaki |
| **Tanks** | Tiger I – first used near Leningrad (1942), decisive at Kursk (1943); T-34 – Battle of Moscow (1941), turning point at Kursk (1943); Sherman – North Africa (1942–43), Normandy/D-Day (1944), advance through France & Germany |
| **Jeep** | All major theaters (North Africa, Italy, Normandy, Pacific islands) from 1941 onward |
| **Helicopters (Flettner Fl 282)** | German reconnaissance in the Mediterranean (1944–45); artillery spotting on Eastern Front |
| **Medicine (Penicillin, Plasma, Atabrine, Sulfa drugs)** | All major campaigns – saved lives at Normandy (1944), in Pacific jungles (malaria prevention), and across Europe |

*Mass Production and Industrial Engineering*

The factories retooled once we were at war to change to different products (in some cases). They were mass producing products for the war effort. For example, Sherman tanks, jeeps, planes, rifles, etc.

Production techniques assisted in the mass production for the war effort. Some of the technology included modular design, statistical quality control, and assembly-line optimization.

*Electronics Miniaturization*

Another concept was making electronics smaller and shock-resistant. This was a step towards modern electronics. Devices such as proximity fuses, radar sets, and fire-control computers were steps towards modern electronics.

# Ethical Implications of Science and Engineering in World War II

World War II was not only a military conflict but also a defining period for science and engineering. Engineers, scientists, and technical professionals played critical roles in developing technologies that shaped the outcome of the war and permanently altered society for the future. While these innovations advanced human knowledge and postwar industry, they also raised profound ethical issues that remain relevant to modern engineering practice. There were many ethical considerations that arose from World War II technological development and their implications for professional responsibility today.

## Dual-Use Technology and Professional Responsibility

Many technologies developed during World War II had both military and civilian applications. Radar, nuclear physics, computers, jet propulsion, operations research, and synthetic materials were developed to meet wartime needs but later became foundational to civilian infrastructure, medicine, transportation, and industry.

The ethical challenge lies in the dual-use nature of these technologies. Engineers often pursue innovation to solve technical problems without full control over how the resulting technology will be used. World War II demonstrated that technical success does not guarantee ethical outcomes. Engineers must consider not only whether a technology is feasible, but how it may be applied, misapplied, or weaponized in the future.

## Civilian Harm and Technological Targeting

World War II marked a shift toward total war, where civilian populations became direct targets. Technological advancements enabled long-range bombing, guided weapons, ballistic missiles, and nuclear weapons. Engineers contributed to increasing weapon accuracy, payload, and reliability, fully aware that civilian casualties were an expected outcome rather than an unintended side effect.

This raises ethical questions about responsibility for harm caused by engineered systems. While military objectives may justify certain actions during war, engineers must confront the moral implications of designing systems whose primary effect is widespread destruction of civilian infrastructure and loss of life.

## Nuclear Weapons and Existential Risk

The development of nuclear weapons introduced a new ethical dimension: the capacity for mass destruction on a global scale. Scientists and engineers working on nuclear research understood the unprecedented power of technology, yet development continued under wartime urgency. The rationale for using the atom bomb was that it would save lives based on the estimated losses that could be incurred on both sides if we invaded Japan.

Following the war, nuclear weapons became instruments of deterrence rather than tactical use. The resulting doctrine of deterrence relies on the threat of catastrophic civilian harm to prevent

conflict. This creates an enduring ethical dilemma regarding whether the existence of such weapons enhances global stability or perpetuates ongoing risk to humanity.

**Scientific Complicity and Coercion**

World War II also revealed ethical failures in scientific practice under authoritarian regimes. For example, Josef Mengele's experiments on concentration camp inmates as an extreme case. In some cases, engineers and scientists were coerced into participating in unethical programs. In others, individuals willingly contributed to projects involving forced labor, inhumane experimentation, or weapons designed explicitly for terror.

These circumstances highlight the limits of the argument that engineers are merely neutral problem-solvers. Professional responsibility extends beyond technical competence and includes moral judgment, even under political or institutional pressure.

**Operations Research and the Quantification of Human Life**

The formal emergence of operations research during World War II introduced mathematical optimization into military decision-making. While this improved efficiency and saved lives in some cases, it also reduced complex human outcomes to statistical variables. Decisions about acceptable loss rates, bombing patterns, or resource allocation treated human lives as numerical inputs.

This raises ethical concerns about dehumanization in technical decision-making. Engineers must recognize the limitations of purely quantitative models and ensure that human consequences remain central to engineering judgment.

**Postwar Accountability and Knowledge Transfer**

After the war, nations competed to acquire advanced scientific knowledge, often recruiting former enemy scientists regardless of their prior conduct. For example, we wanted to prove during the space race that our Germans were better than the Soviet's Germans. Technical expertise was prioritized over accountability in the interest of national security and technological advantage.

This raises questions about professional integrity and whether technical contributions can be separated from ethical responsibility. The legacy of these decisions continues to influence debates about accountability, justice, and the ethical limits of national interest.

**Lessons for Modern Engineering Practice**

The ethical challenges faced during World War II remain relevant today. Modern engineers work with powerful technologies such as artificial intelligence, autonomous systems, biotechnology, and advanced weapons. The lessons of World War II emphasize that engineers are not ethically neutral actors and that professional responsibility includes consideration of long-term societal impact.

Engineering ethics require commitment to public safety, accountability, and informed judgment. World War II demonstrated that technological capability without ethical restraint can produce irreversible consequences. Understanding these historical lessons strengthens ethical awareness and supports responsible engineering practice in the present and future.

## Conclusion

World War II was not only a pivotal military conflict but also a catalyst for unprecedented scientific and technological advancement. The demands of total war accelerated innovation across numerous fields, from nuclear physics and aeronautics to medicine and materials science. Technologies such as radar, computers, jet propulsion, synthetic materials, and the atomic bomb reshaped both the battlefield and postwar society.

Many of the breakthroughs developed under wartime pressure laid the foundation for modern life. Civilian applications of wartime innovations led to progress in healthcare, communications, computing, and transportation. The conflict also redefined the global balance of power and spurred the technological competition of the Cold War, especially in nuclear arms and space exploration.

In examining these developments, it is clear that World War II was as much a war of engineers, scientists, and inventors as it was of soldiers and generals. The legacy of their work continues to influence our world today, underscoring the profound connection between military necessity and technological progress.

## Timeline of Major Events leading to World War II

| Event | Date |
|---|---|
| Christian Hulsmeyer demonstrates early radio detection of ships | 1904 |
| The Treaty of Versailles ended World War I | 1919 Jun 28 |
| Benito Mussolini is appointed Prime Minister in Italy | 1922 Oct 30 |
| Japanese invasion of Manchuria | 1931 Sep 18 |
| Adolf Hitler is appointed Chancellor of Germany | 1933 Jan 30 |
| Federal elections are held in Germany | 1933 Mar 5 |
| Robert Watson-Watt demonstrates practical radar to British Air Ministry | 1935 Feb 26 |
| Italy invades Ethiopia | 1935 Oct 3 |
| Germany remilitarizes the Rhineland | 1936 Mar 7 |
| British Air Ministry begins analytical studies of air defense efficiency | 1937 |
| Japan invades China | 1937 Jul 7 |
| Germany annexes Austria | 1938 Mar 12 |
| Munich Agreement | 1938 Sep 30 |
| Britain's Chain Home radar stations become operational | 1938 Dec |
| Tizard Mission accelerates British-American scientific cooperation | 1939 July |
| Nazi-Soviet Pact is signed | 1939 Aug 23 |
| Germany was the first country to use a jet engine in flight | 1939 Aug 27 |
| Bletchley Park begins wartime operations | 1939 Sep |
| Germany invades Poland | 1939 Sep 1 |
| Britain declares war on Germany | 1939 Sep 3 |
| The Soviet Union invades Poland from the East | 1939 Sep 17 |

| | |
|---|---|
| Germany invades Denmark | 1940 Apr 9 |
| Enigma decryption becomes operationally useful (Ultra intelligence) | 1940 May |
| First British Operations Research Sections formed during the Battle of Britain | 1940 May-Jun |
| Germany invades Belgium, France, and the Netherlands | 1940 May 10 |
| Winston Churchill replaces Neville Chamberlain as Prime Minister of Britain | 1940 May 10 |
| British Ministry of Aircraft Production reorganized under Lord Beaverbrook | 1940 May 14 |
| Evacuation of Allied troops from Dunkirk (France) begins | 1940 May 26 |
| Italy declares war on France and Britain | 1940 June 10 |
| Surrender of France | 1940 Jun 22 |
| Strategic air defense validated | 1940 Jul-Oct |
| The Battle of Britain begins (air war) | 1940 Jul 10 |
| Cavity magnetron shared with US | 1940 Sep |
| Selective Training and Service Act of 1940 is enacted | 1940 Sep 16 |
| Tripartite Pact is signed between Germany, Japan, and Italy | 1940 Sep 27 |
| RAF formally adopts Operational Research for air defense optimization | 1941 Early |
| Lend-Lease Act is passed | 1941 Mar 11 |
| First Allied jet propulsion | 1941 May 15 |
| HMS Hood is sunk by the battleship Bismarck | 1941 May 24 |
| The battleship Bismarck is sunk (scuttled) | 1941 May 27 |
| Ultra used for convoy routing in the Atlantic | 1941 Jun |
| The Germans begin Operation Barbarossa (invasion of the Soviet Union) | 1941 Jun 22 |
| Royal Navy applies Operations Research to convoy escort and anti-submarine warfare tactics | 1941 Mid-year |
| The Atlantic Charter between Roosevelt and Churchill during Atlantic Conference | 1941 Aug 14 |

| | |
|---|---|
| Siege of Leningrad begins | 1941 Sep 8 |
| ASDIC/sonar paired with Operations Research for convoy defense | 1941 Dec |
| Japanese attack on Pearl Harbor | 1941 Dec 7 |
| The United States declares war on the Japanese Empire | 1941 Dec 8 |
| Declaration of war against the US by Germany and Italy, and vice-versa | 1941 Dec 11 |
| US War Production Board established | 1942 Jan 16 |
| Wannsee Conference held in suburb of Berlin | 1942 Jan 20 |
| President Roosevelt signs Executive Order 9066 to allow internment of Japanese | 1942 Feb 19 |
| Doolittle Raid on Tokyo | 1942 Apr 18 |
| Japanese naval code JN-25 sufficiently broken for Midway planning | 1942 May |
| First carrier to carrier battle in the Battle of the Coral Sea | 1942 May 4-8 |
| Liberty ship mass production peaks | 1942 Mid-year |
| Manhattan Project is formally organized | 1942 Jun |
| Beginning of the Battle of Midway | 1942 Jun 3 |
| Beginning of the First Battle of El Alamein | 1942 Jul 1 |
| Anne Frank goes into hiding with her family | 1942 Jul 6 |
| Precision bombing doctrine questioned after heavy losses | 1942 Aug |
| Guadalcanal begins | 1942 Aug 7 |
| Beginning of the Battle of Stalingrad | 1942 Aug 21 |
| The B-29 bomber first flown | 1942 Sep 21 |
| The first successful test flight of the V-2 | 1942 Oct 3 |
| Beginning of the Second Battle of El Alamein | 1942 Oct 23 |
| Operation Torch in North Africa where Allies invade | 1942 Nov 8-16 |

| | |
|---|---|
| The Casablanca Conference begins | 1943 Jan 14 |
| The Germans surrender at Stalingrad | 1943 Feb 2 |
| Operations Research embedded in US Army Air Forces for bomber survivability analysis | 1943 Spring |
| The uprising in the Warsaw Ghetto begins | 1943 Apr 19 |
| Allied shipbuilding output exceeds U-boat sinkings permanently | 1943 May |
| Allied anti-submarine warfare dominance established in the Atlantic | 1943 May |
| Americans and British begin a strategic bombing campaign against Germany | 1943 Jun |
| Proximity fuses are authorized for widespread use | 1943 Jul |
| The Battle of Kursk begins | 1943 Jul 5 |
| The Battle of Prokhorovka | 1943 Jul 12 |
| Operation Gomorrah (Hamburg firestorm) marks area bombing shift | 1943 Jul 24-28 |
| Mussolini resigns as leader of Italy | 1943 Jul 25 |
| Surrender of Italy | 1943 Sep 3 |
| Beginning of the Tehran Conference | 1943 Nov 28 |
| Operation Bodyguard formally approved (D-Day deception framework) | 1943 Dec 4 |
| Allied air superiority achieved over Western Europe | 1944 Early |
| Operation Fortitude deceives Germans on invasion location | 1944 Jan-Jun |
| The Siege of Leningrad ends | 1944 Jan 27 |
| The Allies enter Rome | 1944 Jun 5 |
| D-Day invasion of Normandy (Operation Overlord) begins | 1944 Jun 6 |
| V-1 started being launched against London in response to Operation Overlord | 1944 Jun 13 |
| Battle of the Philippine Sea | 1944 Jun 19 |
| Failed assassination attempt on Adolf Hitler | 1944 Jul 20 |

| | |
|---|---|
| Anne Frank and her family are discovered | 1944 Aug 4 |
| Paris is liberated by the Allies | 1944 Aug 25 |
| Red Ball Express begins supplying Allied armies in France | 1944 Aug 25 |
| First organized kamikaze attacks (Leyte Gulf) | 1944 Oct |
| Beginning of the Battle of Leyte Gulf | 1944 Oct 23 |
| Beginning of the Battle of the Bulge | 1944 Dec 16 |
| Yalta Conference begins | 1945 Feb 4 |
| Beginning of the Allied bombing of Dresden | 1945 Feb 13 |
| Beginning of the Battle of Iwo Jima | 1945 Feb 19 |
| Tokyo firebombing demonstrates strategic bombing peak | 1945 Mar 9-10 |
| German industrial production collapses under shortages and bombing | 1945 Spring |
| Battle of Okinawa | 1945 Apr 1 |
| Death of President Roosevelt | 1945 Apr 12 |
| Beginning of the Battle of Berlin | 1945 Apr 16 |
| Soviet Army surrounds Berlin | 1945 Apr 20 |
| Mussolini is hanged by partisans | 1945 Apr 28 |
| Adolf Hitler commits suicide in his bunker | 1945 Apr 30 |
| Germany signs unconditional surrender | 1945 May 7 |
| Trinity Test in New Mexico | 1945 Jul 16 |
| Beginning of Potsdam Conference | 1945 Jul 17 |
| Operations Research recognized as permanent military discipline at war's end | 1945 Aug |
| Atomic bomb dropped on Hiroshima by the US | 1945 Aug 6 |
| The Soviet Union declares war on Japan | 1945 Aug 8 |

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| Atomic bomb dropped on Nagasaki by the US | 1945 Aug 9 |
| Japan announces unconditional surrender | 1945 Aug 15 |
| Japan signs the official surrender, ending the war in the Pacific | 1945 Sep 2 |
| Demobilization and conversion to civilian industry begins | 1946 Early |
| The United States Air Force is established | 1947 Sep 18 |

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