Technology & the Future

Managing Change and Innovation in the 21st Century

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Technology & the Future: Managing Change and Innovation in the 21st Century

The relentless advance of technology will reshape life in the 21st century. We are entering the Molecular Age -- a technological revolution that will fundamentally change the lives we lead. Many of the technologies of the next half century are already being developed, and when they emerge they will drive the transformation of global economic, social, and political systems, shaping how we live and work.

This book provides both a personal perspective on the impact of technological change over the past half century aand insights into what we are likely to see over the next 50 years. It looks not just at what those changes might be, but also why they occur and how we can assess technological change.

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Published 2014 by
Jericho Hill Interactive
Alfred, NY
USA 14802

3

Technology Life Cycle

All technological innovations follow a common sequence of events as they move from the initial idea to the end of their life cycle. This technology life cycle is divided into two separate periods – the pre-commercial or pre-operational period and the commercial or operational period. The terms "pre-operational" and "operational" are typically used when describing military technologies. "Pre-commercial" and "commercial" are typically used when describing civilian technologies. In this book, the terms "pre-commercial" and "commercial" include "pre-operational" and "operational" unless otherwise noted.

The technology life cycle is a 10-stage process that most technologies go through as they move from their initial conception through commercialization to their replacement by another technology. This technology life cycle was based on two different concepts. The first was the stages used to measure technical progress outlined by James R. Bright in 1979 in his book Practical Technology Forecasting: Concepts and Exercises. Bright proposes an eight-stage process that cover the pre-commercial period in detail but identify only two stages following commercialization. This framework is effective for tracking and assessing technologies through their formative phases but the last two stages are too broad to gain a good understanding of the dynamics of a commercialize technology.

The Abernathy-Utterback model is used as the basis for the five

stages of the technology life cycle that begin with commercialization. This model of technological evolution was developed by Bill Abernathy, a professor at the Harvard School of Business, and Jim Utterback, a professor at MIT's Sloan School of Management. Abernathy and Utterback concluded that technology evolves through periods of incremental innovation that are interrupted by periods of radical innovation. During periods of radical innovation the technology changes rapidly until eventually a dominant design emerges. The Abernathy-Utterback model is quite precise about what happens with the evolution of a technology following commercialization, but does not address its development in the pre-commercial period.

By slightly modifying and linking the Bright model with the Abernathy-Utterback model, a more complete a technology life cycle that covers a technology from its initial conception to its final replacement was created.

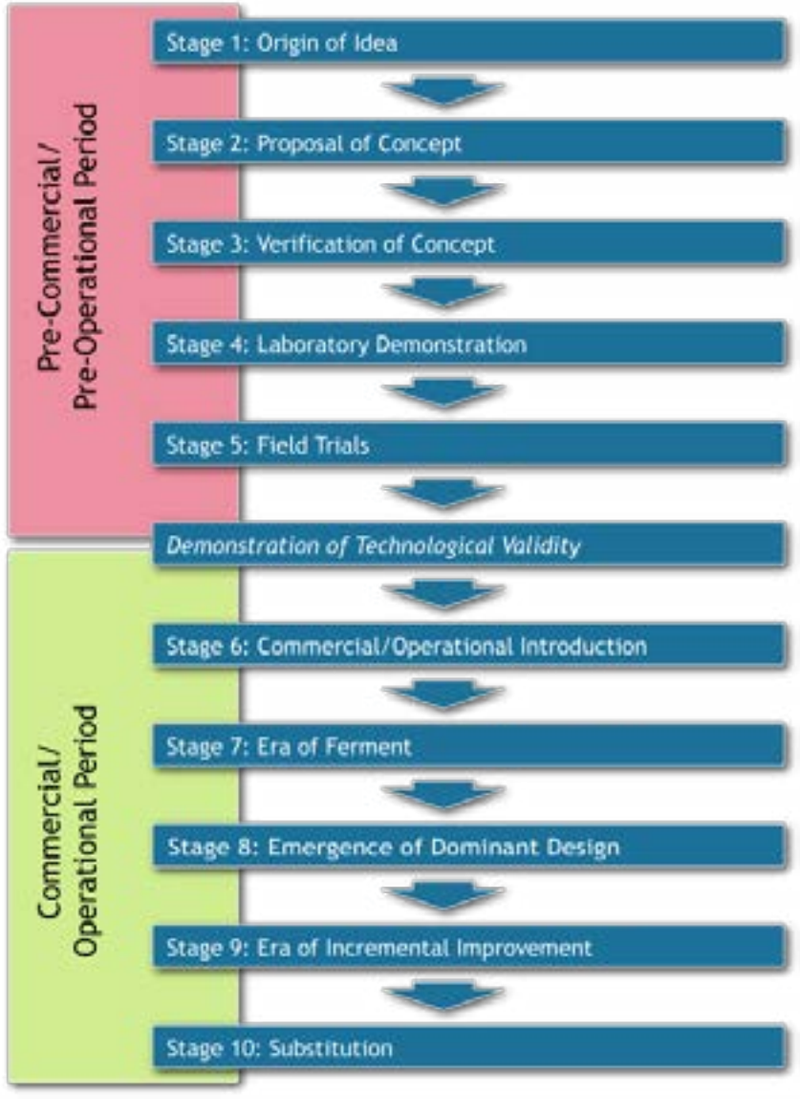
Pre-Commercial/Pre-Operational Period

The pre-commercial or pre-operational period consists of five stages. This period begins with the initial conception of an idea and ultimately ends with field trials designed to demonstrate the viability of the technology. A technology may take decades or even centuries to progress from the emergence of the initial idea to the demonstration of its technological viability. A technology can remain stalled for years, decades, or longer at any stage of this period and many simply fail to make it through the pre-commercial/pre-operational period.

Commercial/Operational Period

The commercial or operational period of a technology's life cycle also consists of five stages, beginning with the commercial/operational introduction of the technology and culminating with its eventual integration or substitution. While it may take many years or decades

for a technology to progress through the commercial/operation period, this typically happens much more rapidly than the pre-com-



The Technology Life Cycle consists of ten stages.

mercial/pre-operational period. As with the pre-commercial/pre-operational period, a technology may stall at any of these stages or fail

completely to make it through the full technology life cycle.

Stage 1: Origin of Idea

Every technological innovation begins with the emergence of a new idea. Breakthrough technologies rarely spring full-grown from the imagination of an individual inventor. Rather, the development of an original idea typically occurs in one of three ways:

- Recognition of a need or opportunity,
- By scientific suggestions based on speculation, hypotheses and inferences made by scientists or engineers, or
- Deliberate or accidental discovery of a new phenomenon or concept.

The conception of the idea is only the first step in a long process that ultimately brings the idea to fruition.

Stage 2: Proposal of Concept

The development of a theory or design concept that outlines a workable technology is the second stage of the technology life cycle. Much trial and error is often needed to develop a theory or design concept. Sometimes earlier concepts are refined or entirely new concepts emerge, replacing older concepts that did not work as well.

Stage 3: Verification of Concept

The basic validity of the proposed theory or design concept is tested during the third stage of the technology life cycle. The verification stage is characterized by one or more experiments that confirms the validity theory or design concept, but a useful technology is not yet developed at this point.

Stage 4: Laboratory Demonstration

The first primitive models of the technology are developed during

the fourth stage of the technology life cycle. Numerous alternative configurations of the technology may be developed during the laboratory demonstration stage as alternative configurations, materials, and variations in scale are tested. Prototypes of the technology may be developed, but they are not yet ready for commercial or operational use.

Stage 5: Field Trials

Prototypes of an innovation are tested in real-world settings during the fifth stage of the technology life cycle. Numerous refinements to the technology are likely to occur during the field trials and many technologies fail at this point.

Demonstration of Technological Viability

At some point during the field trials, the technological feasibility of an innovation may be demonstrated, enabling it to move from the pre-commercial/pre-operation period of its development to the commercial/ operational period. However, just because an innovation is technologically feasible does not mean it is commercially or operational viable.

Stage 6: Commercial/ Operational Introduction

The first commercial sale or (for military technologies) operational use marks the sixth stage of the technology life cycle. The commercial/operational introduction marks the acceptance of the technology as a valid commercial or operational system. The technology, however, is very likely to continue to evolve as a result of its use in real-world applications and in the face of competitive pressures.

Stage 7: Era of Ferment

Shortly after entering operational or commercial use, a new tech-

nology will enter the seventh stage of the technology life cycle. The "era of ferment" is a stage during which the technology goes through a turbulent period of rapid evolution. While it may be clear the new technology offers significant breakthrough capabilities, there is often little agreement about what the major subsystems of the technology should be, how they should be configured, or how they should work together. As a result, the technology can change rapidly and dramatically. At this stage in the technology's life cycle, competition is based primarily on new designs with enhanced capabilities.

Stage 8: Emergence of Dominant Design

The eight stage of the technology life cycle occurs when a dominant design emerges. A dominant design is a single technology or product category that is adopted by the majority of users. The development of a dominant design provides a level of standardization that helps speed the adoption of the technology. It enables producers of the technology to shift their research and development efforts from a search for the appropriate set of characteristics and functionality to incremental improvements in the technology and the processes for producing it, helping drive down product costs and increasing its availability even as the technology's performance improves.

Stage 9: Era of Incremental Improvement

The ninth stage of the technology life cycle is characterized a period of more gradual change. During this "era of incremental improvement", changes to the dominant design typically focus on improving the efficiency and increasing the level of adoption of the technology. During this period, numerous small improvements account for most of the technological progress in an industry.

Stage 10: Substitution

The last stage of the technology life cycle is the point at which the current dominant technology begins to be replaced by a new technology. During this phase of a technology's life cycle, the threat posed by a new technology may at first appear to be relatively insignificant. Cost, performance, or other issues may keep the new technology from immediately dominating the market. Sometimes, however, the new technology may clearly present significant benefits and immediately threaten the dominance of the existing technology

Aviation: An Example of a Technology Life Cycle

The technology life cycle can be applied to almost any technology. Aviation is used here because it has a long history beginning around 2350 B.C.E. and has a significant amount of information about specific milestones in the technology's development. The example ends with the introduction of jet fighter aircraft towards the end of World War 2 because this is where we see the first operational use of a disruptive technology that replaces an older technology.

- **Stage 1: Origin of Idea** – The first known image of a human flying is on a clay seal dating from around 2350 B.C.E. to 2150 B.C.E. Around 1100 B.C.E. the Greek legend of Icarus has human flight at the center of the story. These are just two examples that point to the ancient origins of the idea of human flight.
- **Stage 2: Proposal of Concept** – The systematic research of the principles of flight is reported as early as the 9th century when the Islamic scholar Abbas Ibn Firnas studied birds, bats, and flying seeds before building and flying a glider. Much of that work was lost to history and little is known about these early experiments with flight. In the late 15th

century Leonardo da Vinci also systematically studied birds and bats to build a body of knowledge about flight. He created design concepts for various types of flying machines. It is not known if he actually built any of these machines.

- **Stage 3: Verification of Concept** – Over a period of three centuries the principles of flight were slowly discovered. In 1799 the concept of the modern airplane was first developed and in 1804 the four aerodynamic forces of flight were identified. Throughout the 1800s further experimentation identified other theoretical aspects of flight, ultimately leading to the conclusion that a heavier-than-air flying machine was theoretically possible.
- **Stage 4: Laboratory Demonstration** – Primitive models led to the development of many different types of gliders that demonstrated it was possible to fly. In the late 1800s and the first decade of the 20th century numerous experimental models were developed and tested by the Wright brothers, who used their understanding of aerodynamics to develop better wings, control surfaces, structural designs for their gliders.
- **Stage 5: Field Trials** – In 1903 the Wright brothers made the first short flight of a powered heavier-than-air machine. This was just the beginning of a long process of development and testing of aviation technology to improve range, speed, carrying capacity, and other performance factors.
- **Stage 6: Commercial/Operational Introduction** – The first operational use of aircraft was in 1911 when the Italian military used them for reconnaissance and bombing attacks. At the start of World War 1 all of the major combatants had operational aircraft.
- **Stage 7: Era of Ferment** – Aviation technology went

through a period of rapid evolution in the four years of World War 1. Between 1914 and 1918 many radically different designs for aircraft emerged, some involving variations in such basic elements as the number of wings. Monoplanes, biplanes, triplanes, and even quadplanes were developed. This rapid evolution continued through the 1920s and 1930s, resulting in many different designs and the introduction of such innovations as the use of aluminum rather than wood and canvas, retractable landing gear and enclosed cockpits.

- **Stage 8: Emergence of Dominant Design** – By 1939, when World War 2 began, the basic features and performance of frontline military aircraft had stabilized into a dominant design – a single wing, one internal combustion engine, retractable landing gear, a closed cockpit, and so on. The basic layout for frontline fighter aircraft was the same for all of the combatants during World War 2.
- **Stage 9: Era of Incremental Improvement** – Throughout World War 2 numerous small improvements resulted in performance improvements. However, the basic design of these aircraft remained the same.
- **Stage 10: Substitution** – The emergence of a new technology – the jet aircraft – and its operational introduction late in World War 2 brought an end to piston-powered fighter aircraft. The German ME-262 fighter jet was a disruptive technology; within five years jet aircraft had replaced the older technology.

Tracking what life cycle stage a technology is in can provide numerous insights into the speed, direction, and nature of its evolution. For example, a technology that is still in the laboratory demonstration stage is probably years, perhaps decades away from commercial introduction. A technology that has had a successful commercial intro-

duction will probably experience a period of rapid, turbulent change, which the emergence of a dominant design means incremental improvements rather than radical innovations are likely.