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Engineering the Future, Understanding the Past

A Social History of Technology

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Contents

List of figures

Preface

Today, we face great challenges: climate change; the threatened breakdown of unsustainable energy, mobility, and healthcare systems; growing economic inequality; and security and privacy threats, to name a few. Until a decade ago technologists were still slow to respond to these emerging crises.[1] But that has changed: today, engineering organizations, the engineering sciences, and companies are addressing these challenges. They work on everything from sustainable energy, mobility, and materials to personal medicine, encryption and inclusive innovation. Employers require engineers to understand the societal, business, and user aspects of technology. Employers also require engineers to be equipped to work in multidisciplinary teams that represent different stakeholders. Engineering education addresses these issues in the training of future engineers.[2]

Drawing lessons from the past, *Engineering the Future* contributes to the debate on the role of engineering in an age of great challenges. This book revisits two centuries of social history of technology and engineering. The history of technology as an academic discipline brings together history and engineering. As such, history of technology has always sought to bridge "two cultures"—the sciences and the humanities.[3] Studying the role of technology in history reminds humanities scholars—especially historians—of the ways in which technology and engineering matter in the making of the modern world (for better or for worse). Interpreting engineering in its broader historical and social context also invites engineers to see beyond technology hypes and tech scares. Exploring the history of technology allows us to discuss where the field comes from and where it is going.

This book was originally written to introduce the Eindhoven University of Technology's engineering students to the role of social groups and issues in engineering. The existing broad-strokes social histories of technology in English have been written by American scholars; this book takes into account more of the European experience.[4] The book was made possible by many people's committed efforts. We would like to thank Anthonie Meijers and Johan Schot for laying the foundations of the introductory history and ethics course at Eindhoven University of Technology. We are also grateful to that course's lecturers and students for their valuable insights and comments over the past years. Particular thanks are due to Stathis Arapostathis, Karena Kalmbach, Natasja Leurs, Frank Schipper, Frank Veraart, Geert Verbong, Rosalind Williams, and Anna Åberg for their astute comments on earlier drafts. Obviously, responsibility for this book's interpretations

as well as any factual errors rests solely with the authors. We are indebted to Lisa Friedman for her style editing; Jan Korsten for image editing; Rixt Runia of Amsterdam University Press for her enthusiasm and support; and Lex Lemmens (Eindhoven University of Technology Bachelor College), Lilian Halsema (Department of Industrial Engineering and Innovation Sciences), and Rudi Bekkers (Technology, Innovation & Society group) for their financial support in developing this book. Last but not least, we are much indebted to our historian colleagues who, in the last decades, have re-energized the study of technology's role in European and global history. Without the insights of our colleagues, this book could not have been written.

Erik van der Vleuten, Ruth Oldenziel, Mila Davids
Eindhoven, January 2017

Introduction: Engineering for a Changing World

The world is changing. And so is engineering.

In the past few years, the nature of engineering—as well as its research agenda—has been changing, especially in response to the many crises that haunt our present-day world.

For example, several years ago, a trio of specialists interviewed approximately fifty top scientists and engineers worldwide. The specialists were Rutger van Santen, a computational catalytic chemist; Djan Khoe, an electro-optical communications professor; and Bram Vermeer, a physicist and science journalist. The interviewers inquired about the scientists' and engineers' research priorities for the next twenty years. The answers revealed the belief that cutting-edge technology should address society's major challenges: climate change and energy crises; the threatened breakdown of unsustainable mobility, health, urban, and financial systems; collective and individual security threats such as terrorism and online identity theft, for example.[1]

The scientists argued that technology is a tremendously powerful force that is key to solving these challenges. They reasoned that many of these challenges are deeply technological in nature; modern technology in some way caused or enabled these challenges, and technology has certainly intensified the impact of these challenges. The researchers observed: "Generations of engineers have steadily woven an international web of industries, communications, and markets that has resulted in planetary interdependence … We will now survive together or quite possibly perish together."[2] Technology is implicated in our current crises; technology should therefore be part of the solution, they argued. Accordingly, the scientists and engineers interviewed asked for breakthroughs in these engineering domains: sustainable energy and materials, smart electronics, smart logistics, urban planning, personalized medicine, and cryptography, among others. "We have some serious work to do."[3]

Today, this idea has become commonplace. Humanity faces great challenges, and turns to engineers to solve them. And engineers have answered. For instance, some of the most prominent engineering organizations in the world—including the US National Academy of Engineering, the UK Royal Academy of Engineering, and the Chinese Academy of Engineering—co-organized several Global Grand Challenges Summits, such as those in London in 2013 and in Beijing in 2015. These summits aimed to start an "international conversation on advancing solutions to humanity's grand challenges" and to foster "the dialog among the world's leading engineers and other stakeholders."[4] The key themes were sustainability, urban infrastructure, energy, health, the joy of living, education, and security and resilience. Tackling these issues, it was said, requires "creativity, innovation, passion and sheer intellectual horsepower."[5] "Who better than engineers to lead this charge?" asked Dame Ann Dawling, Professor of Mechanical Engineering at Cambridge and later president of the Royal Academy.[6]

Prominent scientists and engineers have been joined in their efforts by the likes of Microsoft's Bill Gates and leading geneticist John Craig Venter, whose team sequenced the human genome and constructed the synthetic bacterial cell. As Venter said at the 2013 summit: "The world is in need of disruptive change and synthetic biology can provide some of the change that is needed."[7]

As we will see later in this book, the Global Challenges Summits are not alone in pursuing their mission. Others participate throughout the world and across engineering disciplines: professional engineering organizations, technical universities, and technology-based companies. All are attempting to identify social challenges and gauge the future of engineering; many players have adopted similar research and education agendas.

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Emerging technologies, and the prospect of solving social problems through technology, make engineering particularly exciting and important today. Yet the prospect of using technology to address social problems also raises fundamental questions. For example, what decisions can and should engineers make? Will these decisions indeed solve problems, or introduce new ones, as has often happened in the past? In turbulent times like ours, the future is uncertain, as are the consequences of our actions. As such, it is important that engineers learn from the outcomes of similar problems and solutions in their discipline's past.[8] In this book, we look to the history of engineering to draw such lessons.

Lessons from engineering history: Society, Enterprise, Users

Modern engineering emerged roughly two centuries ago. Since then, many have turned to technology to solve social problems. Among those people have been engineers, entrepreneurs, policymakers, and the public. Their experiences teach us relevant lessons. This book addresses several of those lessons.

The first lesson is that engineers have never operated in a vacuum. Engineering has always addressed social challenges. In this book, we distinguish three kinds of social challenges: challenges concerning society, enterprise, and users. Overlaps between them abound. Still, it is useful to distinguish between these categories analytically, for as we will see, each group offers different questions and answers about engineering's past, present, and future.

Throughout history, many engineers have worked on challenges to *society*. These problems were vast indeed. Two centuries ago, structural poverty and hunger, poor health, and poor housing affected multitudes, even in the world's wealthiest countries. With the exception of a small minority of elites, most of the world's population lacked adequate water, food, and shelter; energy and mobility; healthcare, and personal security. Expanding cities were on the verge of breakdown. The average life expectancy was lower than 35 years of age; in cities, that estimate was even lower. As we will see in this book, the profession of modern engineering emerged to tackle such challenges: engineering has continuously interacted with society's crises and challenges.

Just as some engineers have worked on societal challenges, others have worked on challenges to *enterprise*. These engineers saw technology as a great business opportunity and/or as a way to improve business processes or working conditions. Many engineer-entrepreneurs transformed societal challenges into business models and new technological solutions. The business challenges of engineering became ever more important as technology-based companies—in railways, communications, energy, materials, pharmaceuticals, ICT, and so on—came to dominate our business landscape.

Yet another group, *users*, found technology empowering, purposeful, or just plain fun. While using or playing with technology, users also promoted or changed technology. Often, users themselves became innovators. For example, user communities built their own bikes and cars in the 1880s and 1890s, do-it-yourself radios in the 1910s, and self-made personal computers and wind turbines in the 1970s—all before these technologies became successful commercial products. Today, users make weighty contributions to the development of open-source software, games, and apps. Users also contribute to housing solutions as well as many other fields.

Successful innovation—including innovation that has helped solve major social challenges—has often been relevant to society, relevant to enterprise (as in presenting a viable business model), and relevant to users. This is why engineers from this point forward are expected to have an understanding of these social processes. In this book, we explore the many roles played by society, enterprise, and users in engineering science and practice. How have these roles affected the emergence and development of the engineering profession? Conversely, how has engineering shaped history? And how are society, enterprise, and users responding to the challenges of today?

Technology: Dream and nightmare

The second lesson we can draw from engineering history is that some technologies were wildly successful while others were dramatic failures. In the most discouraging cases, engineers have seen the work of well-intentioned colleagues turn into technological nightmares.

When it came to solving society's immense challenges, technology has indeed helped; but the same technologies that improved the quality of life were also used to destroy life. For example, the same scientists who developed fertilizers that helped feed people also produced poison gas. Another example of technology's double-edged nature: information technologies like the internet promised to democratize information, but that self-same technology also enables surveillance, cybercrime, and the radical loss of privacy.[9]

Regarding enterprise, consider the realities of failure in a business context. For every successful technological entrepreneur, for example, many others have gone bankrupt. Most attempts to innovate have failed. Specifically, the majority of research projects have failed. When they have led to patents or products, the reality is that most patents have rarely been cited or renewed. In fact, most products never reach users' hands.[10]

Historically, when innovations *have* reached users' hands, those very innovations could also pose new risks to their users. For example, early refrigerators and freezers met a huge social challenge: these appliances helped to conserve food. The early refrigerators and freezers came with the liability of doors with latches, however. Children playing hide-and-seek got trapped and suffocated in abandoned refrigerators and freezers. Only after a media outcry were engineers prompted to replace the life-threatening latches with push doors. Another example: scientists developed antibiotics to save lives, but unwitting overuse of antibiotics has fostered dangerous new and resistant bacterial strains that threaten patients' lives. Indeed, well-intended inventions and innovations have sometimes had unintended, completely unexpected, negative consequences for users.[11]

Such unintended negative consequences leave us with a dilemma: the "dilemma of control." Chemist and philosopher David Collingridge coined this phrase in 1980. Today, it is known as the "Collingridge dilemma."[12] When a given technology is young (such as the automobile in the time of Henry Ford), the direction of the technology's development can still be influenced. In the early stages of development, however, we cannot yet know about long-term negative consequences: they have simply not yet materialized—or are not yet considered problematic.

Conversely, when that technology has matured, its negative consequences have materialized. By then, however, changing the technology is extremely difficult and expensive: standards have already been set, factories and supply lines established, workers employed and trained, and markets developed. Users may have built their daily lives around the new technology, and they may earn their living in factories that produce the technology, for example.

This dilemma is historical; change—or the lack of change—over time is a crucial variable in historical outcomes. And today, this dilemma presents itself with renewed urgency. For, as described above, it is past technological solutions that have created many of our present-day social and environmental challenges. Certain past solutions have become current problems. This raises the question of whether today's solutions will generate complex new problems ten, twenty, or fifty years from now.

We cannot know the future, but we can access the past. In this book, we seek to better understand such problems. We pose the questions: How could technologies that once promised to *solve* human challenges *intensify* those challenges? By what mechanism did dreams turn into nightmares? And what did that mean for engineering?

Engineering for a changing world

A third major lesson that we draw from engineering history is how to engineer for an ever-changing world—and a future that we cannot know.

Engineers of the past have asked themselves the same questions that we ask today: How can we solve social challenges, while avoiding new nightmares in an unknown future? How can we best cope with technology's double edge as a cause of—and solution to—social and environmental problems? We know that society, enterprise, and user dynamics are all crucial in such processes. But how can we include these dynamics in technological decision-making and design? And who should lead that effort?

In this book, we outline two approaches that past engineers developed to build better futures without lapsing into nightmares: the technocratic approach and the participative approach. These were contrasting ways of trying to fulfill technology's dreams—and avoid its nightmares. Each approach was widely respected in its historical context; each holds lessons for today.

According to the technocratic approach, engineers and other experts were given the mandate to identify and address social challenges on behalf of society, enterprise, and users. Citizens, politicians, company managers, and others gave engineers this mandate. According to the technocratic philosophy, multidisciplinary teams of experts use the scientific method to identify relevant social issues and develop optimal solutions. Striving to make better technological choices, these experts objectively model and weigh the pros and cons of technological options. The technocratic approach proved appealing and powerful. But as we shall see, it also received copious criticism.

The participative approach emerged in response to the criticism of technocracy. According to the participative philosophy, experts alone should not identify issues—and make choices—on behalf of others. Instead, stakeholders representing society, enterprise, and users themselves should take part in the decision-making and design processes. For example, medical personnel or patient associations, car drivers, local citizens, consumers, and environmental groups might participate in technological decision-making, or work closely with engineers in the innovation process. Like the technocratic approach before, the participative approach prevailed—and proved to have its own set of pros and cons.

This book explores how these contrasting approaches to technology came about; how they operated, and the roles engineers played in each. What were considered their strengths and weaknesses? And if neither approach was considered the perfect solution, can we identify attempts to combine aspects of both models to meet today's challenges?

The structure of this book

This book is a history of the modern world observed through the lens of technology and engineering. To show that the past holds clues to the future of engineering, we have divided this book into four periods. The dates we use are approximations only. In the real world, periods overlap, and every period is complex and contradictory. Using approximate periods lets us explore specific lessons and questions, place the development of engineering in temporal context, and see how engineering has changed over time.

Chapter 1, *The Age of Promise* (*circa 1815-1914*), introduces the social aspects of engineering. This chapter addresses the question of how challenges relevant to society, enterprise, and users came to engage engineering science and practice—and vice versa.

Chapter 1 begins in 1815, when the long Napoleonic Wars ended. We see that, despite the newly-won peace, most people still lived in poverty and misery. What changed was that, inspired by the scientific and industrial revolutions, a new hope arose: that modern technology could overcome the problems that had plagued humans for millennia. In keeping with this belief, a new class of technologists set out to work on providing sufficient and high-quality water and food, shelter and clothing, energy, mobility, information, medical care, and much more. Entrepreneurs captured the opportunities provided by modern technologies to develop a new type of company—the technology-based company. Users became fascinated by the potential of novel technologies, and they, too, became innovators. These efforts ignited a wave of technological breakthroughs never before seen.

This technological optimism endured throughout the Age of Promise, despite occasional setbacks and critiques of technology. The Age of Promise inspired the development of engineering as we know it today. This period provides us with a unique opportunity to examine the role of society, enterprise, and users in setting innovation agendas—and in the birth of modern engineering as a discipline and a profession.

Chapter 2, *The Age of Crisis* (*1914-1945*), addresses the question of how technological promises and dreams could collapse into nightmares. The chapter examines the dynamics of technology's negative consequences. This period in history is particularly suited to studying how once-promising technologies became complicit in major crises. In 1914, after the outbreak of the First World War, the technological optimism of the prewar period evaporated, leaving behind a widely shared sense of global crisis. The time that followed was characterized by two world wars and the global economic crisis of the Great Depression. Some call this period a "thirty-year crisis."[13] Its global scale and horrors were unprecedented, and many blamed technology. It was, after all, technology that had promised to benefit humankind, but during wartime, technology was turned against humankind. For in this period, engineers and scientists repurposed technologies. Railroads, airplanes, cars, chemicals, automatic control systems, nuclear fission—all of these were implicated in the killing of tens of millions of people. During peacetime, technology became derailed in other ways. In the context of large-scale enterprise, for example, innovations like the conveyor belt and scientific management turned many workers' lives into nightmares. During the Great Depression, as bankruptcies and unemployment spiked, technological pessimism became the norm. Chapter 2 analyzes the mechanics of how one person's dream could turn into another person's nightmare. We also outline different kinds of nightmares—dark turns for society, enterprise, and users.

In Chapter 3, *The Age of Technocracy (1945-1970)*, we address debates about how to build better futures without lapsing into nightmares, and who should lead such an endeavor. After 1945, many groups agreed that politicians and businesspeople were not necessarily equipped to direct the innovation process with sensitivity. Allegedly, politicians had used technology to wage wars. Greedy businesspeople had used technology to exploit workers and to crash the world economy. Then, as now, technical experts were called on to take charge: engineers, architects, planners, and other professionals were central in technological decision-making and implementation. Using the scientific method, these experts were expected to make better, more objective choices on behalf of society, enterprise, and users. Chapter 3 also discusses the changes in engineering ethics and education that aimed to prepare engineers for acting on behalf of others.

Chapter 4, *The Age of Participation (1970-2015)*, focuses on an alternative to technocracy: the participative approach. Here, we continue to investigate the question of how technology's promises can be realized and its nightmares avoided.

In the Age of Participation, the argument for technocracy was reversed. Many different stakeholders claimed to know their own needs better than the experts who acted on their behalf. For this reason, spokespeople for society, enterprise, and users sought to participate directly in technological decision-making and design. This was an era of participatory innovation and user-centered design.

In the epilogue we explore how these legacies and lessons can inform current debates on engineering the future. The epilogue traces how scientists and engineers today define current social challenges for engineering, and how—in their view—engineering must adapt if it is to answer to these challenges.[14] We apply the lessons described in this book to make sense of—and inform—this debate.