MANAGING TECHNOLOGICAL INNOVATION & ENTREPRENEURSHIP

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**To Paula,
David, and Kay**

Preface

Man is limited not so much by his tools as by his vision. Historians tell us that the notion of the earth as round had been discussed for five hundred years before Columbus' time. What Columbus did was to translate an abstract concept into its practical implications.

Richard Tanner Pascale and Anthony G. Athos, **The Art of Japanese Management.**

The declining economic growth rate, coupled with high inflation, and the growing unemployment of the last decade, as well as the impact of Le Defi Japonais, has aroused both public and business concern for technological innovation. As a result of much research performed since the 1950s, the complex technological and socioeconomic process whereby a technological invention is converted into a socially useful and commercially successful new product is now less obscure than it was a generation ago. This improved understanding is of little practical value unless it is disseminated to present and future innovation managers through the education system. This requirement raises another issue. Managers have displayed a historic "technology-aversion"[1] so that the management of technology has been a neglected subject in both the management and engineering schools of the universities. Consequently, the management and engineering educational systems have evolved with largely separate languages and cultures. If technological innovation is to sustain future economic growth and employment in competitive international markets, the gap between these two cultures must be bridged by individuals capable of effectively managing the process. The issues and problems involved have been discussed in two specially convened conferences on the subject in the United States[2] and Canada.[3] It is sometimes argued that individuals without prior engineering or science backgrounds cannot become effective technological managers. However, as Skinner points out, individuals without such technological backgrounds can manage technology, provided they

> *can learn to understand and deal effectively with the technology of their industry....What is usually sufficient is a framework consisting of a few basic concepts and a set of questions that lead to the acquisition of that knowledge and those insights needed by a manager.*[4]

The purpose of this book is to help bridge the gap between management and engineering educational systems by providing such a framework to future and present technological innovation managers with or without engineering/science backgrounds. The book has grown out of my experiences developing and teaching courses on Managing Technological Innovation and Entrepreneurship to mixed classes of business (mainly MBA), engineering, and science students from the senior undergraduate to the postdoctoral level.[5] The book can therefore be used as a required text for similar or related one-semester courses in management/business, engineering, and science schools of higher education. It could also be used on related extension/postexperience courses. Alternative course frameworks, and so forth, are discussed in teaching notes provided by the publisher. The book is also written for professional readers, that is, technological managers and entrepreneurs in high-technology firms, research and development (R & D) professionals and managers in both company and government laboratories, and administrators in government agencies responsible for stimulating and regulating high technology.

Chapter 1 begins with three examples of the innovation-entrepreneurship process to illustrate the well-founded contention that it is much more than scientific or engineering invention. Chapter 2 offers some conceptual frameworks for viewing the process congruent with that contention. Chapters 3 through 6 view the innovation-entrepreneurship process from the corporate-general management perspective. By definition, a high-technology business must be technology based. Traditionally, this technological base has been viewed rather narrowly as "engineering" or "R & D" versus "manufacturing" and "sales." In chapter 3 a description of the technological base of a company is provided which is broad enough to encompass the requirements of the process, to provide a factual background to later chapters. Chapter 4 begins by arguing that corporate management's responsibility to stimulate and manage innovation creates the need for an innovation management function and for technological strategies that permeate the organization. It discusses the alternative technological strategies which may be pursued by a company. Technological and social forecasting techniques now used to aid the long-term planning of innovation are reviewed in chapter 5. These days, everyone accepts that innovations must be evaluated to identify potentially harmful impacts on individuals and the ecological and social environment. Chapter 6 briefly discusses procedures for conducting technology assessments and for developing environmental impact statements for prospective innovations.

Chapters 7 through 12 deal with the R & D setting of the process. Chapter 7 briefly discusses the overall organization, budgeting, and planning of the R & D activities in larger companies. R & D management has both behavioral and technicoeconomic aspects and each are dealt with in turn. Chapter 12 also outlines the alternative career development paths available to scientists and engineers and so may be of specific interest to readers who are contemplating a career change from R & D to management. Chapter 13 moves to the operations setting and discusses the problems of transferring technological know-how from an R & D to a production environment.

Chapters 14 through 16 focus on the entrepreneurial aspects of the process. Chapter 14 discusses the important role that successful, growing high-technology companies play in generating economic wealth and jobs. It discusses the "spin-off" phenomenon, notably associated with Silicon Valley in California and Route 128 in Massachusetts. The success of a "spin-off" is markedly dependent upon the entrepreneurial aptitudes and skills of its founders. Therefore, the personality and biographical characteristics of technological entrepreneurs are examined.

Many scientists, engineers, and technological managers employed in larger companies, government, or universities aspire to set up their own high technology businesses, possibly to exploit their own inventive ideas commercially. Chapter 15 examines, in some detail, the problems, pitfalls, and rewards of setting up a new high-technology venture. Clearly larger high-technology companies do not wish to lose all their inventions to spin-off ventures. Furthermore, innovation requires entrepreneurship to succeed in large as well as small companies. The approaches that established companies have taken to sustain entrepreneurship are discussed in chapter 16. The book then concludes with brief comments on the overall management of the technological innovation-entrepreneurship process.

I have included fairly extensive literature citations to support the observations in most chapters, for readers who wish to explore individual topics in more depth. I suggest that they be ignored in a "first reading" so that the gists of the discussions can be followed; then, if required, they can be consulted later according to the reader's specialist interests. I also apologize to those writers whose works have not been cited. The volume of literature available precludes the citation of all the important contributions that have been made in the field. Since the book focuses on the innovation-entrepreneurship process at the individual firm level, I have excluded discussion of public policy aspects of the subject and the relationship between innovation and long waves in world economies. These important (but contentious) topics are discussed in more specialized texts[6,7] and I do not think I could give them sufficient space to discuss them adequately here. For the same reasons, I have excluded discussion of the impact of government regulations on patterns of industrial evolution. Such impacts (notably within the automobile and pharmaceutical industries) have also been discussed extensively elsewhere.[8,9,10]

No book is written without help from one's students and colleagues. I should like to express my thanks to the 200 to 300 bright, mature, and industrious students who have made teaching my course such a pleasure (for me anyway!). I am sure some of their ideas have "spun off" here! I also thank Tom Clarke for stimulating my interest and providing an excellent bibliography in the field,[11] Dr. David Othen, and two unnamed reviewers for their many helpful comments. Needless to say, all the faults are my own. Finally, I thank Marilyn Taylor of Dalhousie University, Caroline Morse, and others for their heroic efforts in typing successive manuscripts, and Ann Mohan and her colleagues at Reston for converting the final manuscript into a finished product.

Alvin Toffler has described education as a vision of the future. It is often claimed that the age of the heroic inventor-entrepreneur is past, but the evidence of the recent explosive developments in the solid-state electronics and computer industries suggests otherwise. If this book helps just one individual to become a successful technological entrepreneur who creates satisfying employment and products for others, it will have been worth it.

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Contents

Part 1

The Technological Innovation Process

Part 1 describes the technological innovation process. It begins with three illustrative examples. It then examines Bright's treatment of the process. Kuhn's and Popper's treatments of the evolution of scientific knowledge are discussed and linked to more recent treatments of technological evolution by Abernathy-Utterback and Sahal. These treatments provide a framework for viewing the process in the corporate setting.

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Prologue: The Technological Innovation Process: Three Illustrative Examples

It is a little like playing poker when it is the only game you want to play and all you know about the game is that the deck is stacked. You don't know how it is stacked but it is stacked and you must play.

Monte C. Throdahl, senior vice-president, Monsanto Co., on the innovation process. Untitled presentation in Dwight M. Baumann (Ed.), **National Conference for Deans of Business and Engineering**

1.1 Invention and Innovation

In the Preface, I implied that general managers of high-technology businesses have a responsiblity to nurture a continuous succession of new products, based upon a continued succession of technological innovations, and therefore need to be familiar with the innovation process. I also suggested that students of science, engineering, and management who plan (or have already started) to pursue careers in high-technology industries should recognize the main features of this process, particularly if they aspire to reach senior/general management positions or set up their own independent high-technology business later. Therefore to begin, we will examine the process in a little detail to identify the combination of elements required to generate a commercially successful technological product.

Most high-technology companies are "science based" in that their innovations develop out of new ideas and inventions generated by scientific activity, either within their own R & D function or elsewhere. However, at the outset, it is important to recognize the distinction between scientific *invention* and technological *innovation*. A scientific invention may be viewed as a new idea or concept generated by R & D, but this *invention* only becomes an *innovation* when it is transformed into a socially usable product. Laypersons, probably because of the mystique that surrounds science, generally view invention as a relatively rare event and assume that once it has occurred, the process of innovation can be completed in a straightforward manner. In actuality, the converse situation pertains here. All who have worked in R & D will agree that although it is intellectually and emotionally demanding and frustrating, even so the R & D community is quite prolific in generating inventions, and companies can rarely afford to fund all promising R & D projects (see chapter 2, section 2.3). It is the subsequent path to technological innovation that is typically fraught with numerous obstacles to be overcome, if the R & D invention is to be commercially successful.

Managing the innovation process may perhaps be compared with breeding and training a horse to finish in the first three places in the English Grand National or other such steeplechases. Although many horses may be bred and trained to come under "startersorders," in any year only three horses perform well enough over the fences to win the first three places in the race and to win prize money for their owners and bets for their backers. Managing the innovation process in larger companies essentially requires breeding a stable of promising R & D inventions, some of which are developed into product innovations in the expectation that they will prove to be commercially successful "winners."

To illustrate some of the features and obstacles of this innovation process, three examples will be given. There are numerous other cases and research studies cited in the literature, two of the most useful of which are Layton et al. and Langrish et al.[1] Pilkington describes his personal experiences in pioneering the development of the float glass process to commercial success and so presents innovation through the eyes of the innovator.[2] Several examples are also described in a special issue of *Research Management,* one of which is included below.[3]

1.2
Marconi and the Development of Radio Telegraphy

The main sources of historical material in this section are Baker and Donaldson.[4]

Radio grew out of what is now called experimental and theoretical physics. Its origins can be traced back to the "science" of classical Greece as well as China, but the foundation was laid by Dr. Humphrey Gilbert, physician to Elizabeth I, who really began the systemic scientific study of the phenomena of electricity and magnetism. Human knowledge of the properties of these phenomena grew steadily between the sixteenth and nineteenth centuries, but it was Michael Faraday who first discovered an interrelationship between the two of them. Like many brilliant experimental physicists, Faraday was no mathematician, and it was James Clerk Maxwell who provided the mathematical formulation of this interrelationship with his electromagnetic field theory, including the proof of Maxwell's equations and the existence of electromagnetic waves. Heinrich Hertz provided the experimental verification of the existence of these waves, Sir William Crookes suggested their potential utility as communication tools, and Sir Oliver Lodge provided a practical demonstration of their use in a lecture at the Royal Institution in 1894. By this time, numerous inventive scientists and engineers were exploring and experimenting with the properties of this promising new tool.

Technological innovation typically requires the collaborative effects of numerous workers, but often its ultimate success can be attributed to the sustained efforts of one or more inventor-entrepreneurs who pioneer the development of a new high-technology industry. The inventor-entrepreneur is twice-blessed by Providence with both technological and commercial creative skills and has the vision, capability, and energy to improve upon and commercially exploit an invention. Examples of such inventor-entrepreneurs are Alfred Nobel (dynamite), W.H. Perkin (aniline dyes), Herbert Dow (industrial electrolysis), Alexander Graham Bell (the telephone), and Thomas Edison (electric light and power supply). Such a role can be credited to Marconi in the development of radio-telegraphy.

Guglielmo Marconi was born in 1874 in Bologna, Italy, of Irish and Italian parents. His mother was Irish, born Annie Jameson and member of the famous Irish whiskey family, and his father was a well-to-do Italian landowner and businessman. It seems reasonable to conjecture that Guglielmo's family's business background influenced his entrepreneurial outlook (see chapter 14 for a discussion of this factor). He was educated in England and Italy, studied physics at the university, and conducted experimental work under Professor Righi of the University of Bologna. He displayed inventive skills from an early age and, having read the work of Hertz, produced a crude form of wireless communication when he was only twenty-two years old. He quickly recognized the potential utility of wireless telegraphy in ship-to-ship or ship-to-shore communication where wired telegraphy was obviously impossible. He therefore offered to demonstrate his invention to the Italian government, but it was disinterested. Acting upon the advice of the Jameson family, he decided to pursue his ideas in Britain—the home of the world's largest mercantile fleet and Queen Victoria's Royal Navy, and where his mother's family connections might prove useful.

Once residing in England, he made contact with other workers in the field and began a program of practical demonstrations of wireless communication to various British government departments in

1896. In 1897 he filed the first patents for wireless telegraphy which were held by the Wireless Telegraph and Signal Co. Ltd, which he founded and capitalized in the City of London in that year. It had a nominal capital of 100,000 £1 shares of which Marconi held 60,000. The remaining 40,000 were sold in a public issue yielding £40,000 which after £15,000 start-up expenses, provided the first £25,000 of working capital. Thus began a decade and a half of unremitting and frustrating efforts to establish the embryonic innovation. Marconi quickly allied himself with other talented scientists, engineers, and businessmen and filed or purchased a succession of patents that appeared crucial to the technological development of radio telegraphy, including Dr. (later Sir) J. A. Fleming's* development of the thermionic diode, based upon earlier work by Thomas Edison.

Throughout this period, Marconi was punctilious in maintaining the technological integrity of his company, never publicizing new inventions until they had been fully proven, never making promises that he could not "deliver." In his choice of public demonstrations of wireless communication, he did display a considerable flair for "publicity," however. By 1898, he had established wireless intercommunications between Bournemouth (in southern England) and the Isle of Wight, 14.5 miles away. In the winter of that year, the eminent Victorian statesman, William Ewart Gladstone, lay dying in Bournemouth surrounded by the world's press corps. This event could be compared to the week prior to the death of Sir Winston Churchill sixty-seven years later. Unfortunately, a winter snowstorm hit southern England, severing wired telegraphic and telephonic communication between Bournemouth and London, so the reporters were unable to file their latest reports of the stateman's sinking health to their newspaper offices in London. Marconi quickly determined that wired telegraphic or telephone services (via undersea cable) were still maintained between the Isle of Wight and London. He therefore allowed the press corps to file their reports by *wireless* communication from Bournemouth to the Isle of Wight and thence to London. This action doubtlessly won him many friends amongst the media people of the day.

The Isle of Wight was to provide him with the site for invaluable publicity again in the summer of that year. The Prince of Wales was convalescing from an injury aboard a yacht moored a few miles off that island. Queen Victoria who was resident at Osborne House on the island at the time naturally wished to be kept informed of her

*There is an interesting parallel between the invention of the diode tube and the discovery of penicillin. Both were invented or discovered fortuitously when the researchers were trying to solve other problems and initially remained unexploited. The author is unaware whether the developer of the diode tube and the discoverer of penicillin were related.