Microcomputers

A Technology Forecast and Assessment to the Year 2000

Microcomputers: A Technology Forecast and Assessment to the Year 2000

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A WILEY-INTERSCIENCE PUBLICATION

JOHN WILEY & SONS, New York • Chichester • Brisbane • Toronto

Library of Congress Cataloging in Publication Data

Wise, Kensall D 1941

Microcomputers : a technology forecast and assessment to the year 2000.

(Wiley series on systems engineering and analysis)

"A Wiley-Interscience publication."

Includes index.

1. Microcomputers. 2. Technological forecasting. I. Chen, Kan, 1928– joint author. II. Yokely, Ronald E., joint author. III. Title.

QA76.5.W57 001.6'4'04 79–18186

ISBN 0–471–04780–5

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

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Preface

Microcomputers are fast emerging as the technology of the 1970s. They are finding their way into everything from televisions to washing machines, microwave ovens to automobiles, and pocket calculators to aviation avionics. It now appears that few fields of human endeavor will remain untouched by this rapidly advancing technology and some social historians are suggesting that the inexpensive microcomputer may well rank as the third major cultural invention of the twentieth century, following the automobile and the television.

This book is about the future of microcomputers—computers contained in a single slice of silicon measuring a fraction of an inch on a side. The technology of microcomputers is relatively new, but is making very fast progress. What is in store for the future development of microcomputers? How will microcomputers affect our society? These are questions important to many people, especially those who must make choices and decisions on the basis of the answers to these questions. Of course, nobody can give complete accurate answers to any questions about the future. The best one can do is to make informed judgments.

In this book, informed judgments are made about future microcomputer technology and its impacts on society for the period 1976 to 2000. The basis of judgment is a synopsis of physical and engineering principles, pertinent literature review, and interviews with knowledgeable persons at the forefront of microcomputer development and applications. The forecasting of microcomputer technology includes that of microprocessors, memory, peripherals, and software. To put the forecasting in a proper and broader perspective, the forecasts of microcomputer components are combined into forecasts of microcomputer system characteristics for two typical applications. Since technology does not exist in a societal vacuum, the forecasts are conditioned by alternative sets of plausible assumptions of future socioeconomic constraints. The same constraints also provide the contexts for an assessment of potential microcomputer impacts on society. Because of the pervasiveness of microcomputer impacts, they are

described in broad brushes for a few plausible alternative futures, and the higher-order impacts and cross impacts are traced in a specific sector—the national aviation system. It is believed that the reader can easily understand the approach and use it to trace the higher-order impacts of microcomputers in any specific sector of interest.

The *substantive* results in this book are intended for a wide range of readers in the computer field—manufacturers, users, researchers, teachers, students, hobbyists, and, above all, technology planners and policymakers in both the private and public sectors. The forecasting and assessment procedures and assumptions are made quite explicit, so that the results can be easily modified by any reader who desires to change some of the original assumptions. To the extent that forecasting and assessment *methodology* contains innovative elements (for example, the use of alternative futures as integrative threads), the book should also be of interest to practitioners and students of technology forecasting and assessment irrespective of their interest in microcomputers per se.

The bulk of the material in this book was generated under a 1976–1977 study conducted by the Onyx Corporation for the Federal Aviation Administration (FAA), Office of Aviation Policy, Policy Development Division, Systems Concepts Branch (contract DOT FA76WAI–609, Task Order 9). The main objective of the study was to assess the impact of microcomputers on the national aviation system, especially in respect to the "S3E" goals (Safety, Energy, Environment, Economics). The authors would like to acknowledge the valuable advice and assistance given by the FAA officials, especially C. Wesley Carson, Lynn Jackson, and Kenneth Harris, and are indebted to the FAA for its permission to use the study results in the preparation of this book.

Other nongovernment contributors to the book were Kenan P. Jarboe, who provided substantive work on the technology assessment; Karl L. Zinn, and Alfred Adler, who developed the microcomputer software technology forecast; Robert F. Lyjak, who analyzed specific microcomputer applications in aviation; and, last but not least, the late F. Thomas Ayers, Jr., who made invaluable contributions during the initial phases of the project. The efforts of these individuals are gratefully acknowledged.

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July 1979

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Microcomputers: A Technology Forecast and Assessment

Since the advent of the first stored-program electronic computer in the 1940s, computer technology has undergone rapid and continuous change. During the 1950s transistors replaced earlier vacuum tubes as the basic logic elements in such machines, and in the 1960s transistors were replaced by integrated circuits, in which many transistors, resistors, and capacitors are formed on a single crystal of silicon. With each technological development, computers have become smaller, faster, and less expensive. Improvements have been measured in orders of magnitude and have been rapid, and the combination of increased functional capability and decreased functional cost has led to an increasing proliferation of computers in a variety of applications. During the 1950s and 1960s, most designs were oriented toward the development of large, high-speed, highly centralized computers in applications ranging from general computation to telephone switching. The impact on society in general was significant but subtle.

By the early 1970s, integrated electronics had developed to the point where the number of electronic components that could be integrated on a single chip of silicon was several thousand. This level of integration was sufficient to allow complete processors for calculators and small computers to be integrated on a single silicon chip measuring typically 3 to 5 mm on a side. The term *microprocessor* was quickly applied to these new devices, and as technology evolved still further, permitting significant amounts of memory to be included on the processor chip, the term *microcomputer* was applied to these still more densely integrated systems.

The introduction of microprocessors and microcomputers represents an important turning point in the development of digital computers. The availability of extremely small, inexpensive, computers having significant processing power and versatility has allowed stored-program control and data processing to be extended into even the smallest electronic instru-

ments. Solid-state integrated electronics, led by microcomputers, is now having a substantial impact on many diverse fields, ranging from industrial process control to health care and transportation. Computers are now becoming decentralized, with many dedicated microcomputers replacing larger centralized and time-shared machines. Portable calculators are perhaps the most visible example of this computing revolution, but in spite of their anticipated effects on education and computation, they are relatively unsophisticated examples of the present technology.

The development of technology for large-scale system integration continues at a rapid pace, with the number of components that can be integrated on a single chip doubling nearly every year. If these developments continue very far into the future, few fields of human endeavor will remain untouched by the microcomputer. The pace of past developments makes it essential that future progress be anticipated so that informed policy decisions can be made and to ensure that the maximum benefits from the technology can be realized. This book is an attempt to anticipate the future of microcomputers and to illustrate how some of its impacts can be assessed. Although completely accurate predictions of the future are impossible, informed judgments can be made. The remainder of this chapter will describe the methodology used to realize the informed judgments that are developed in succeeding chapters.

1.1 TECHNOLOGY FORECASTING AND ASSESSMENT

The primary purpose of technology forecasting and assessment is to anticipate rapid technological changes in order to make wiser and more timely decisions, as compared to the alternative of waiting for the changes and reacting after the fact. There is nothing new in human engagement in such anticipatory activities, but it was not until the 1960s that technology *forecasting* emerged as an interdisciplinary and widely acknowledged field. Technology *assessment* followed about a decade later.

Technology forecasting has been defined as a reasonably definite statement about the future state of a technology, usually contingent on certain assumptions about the environment [1]. Technology assessment has been defined as the systematic study of the effects on society that may occur when a technology is introduced, extended, or modified [2]. Since the assessment of future developments in a technology cannot be done without some specific description of these developments, technology forecasting is frequently embodied in technology assessment. However, when the forecasting activity is a major portion of the total effort, as is the case with analyses described in this book, technology forecasting is discussed as a separate activity for emphasis.

In Western industrialized countries, technology assessment often emphasizes those impacts of technology on society which are unintended, indirect, and delayed. Thus, the side effects as well as the primary impacts of technology are to be identified and analyzed in technology assessment. This is necessary since the side effects of technology are often as important as, if not more important than, its primary impacts. For example, although the primary impact of the automobile was a rapid increase in the speed and mobility of ground transportation, the side effects of the automobile have had significant social consequences—urban sprawl, air pollution, changes in life-style, and so on. Similarly, one can think of the side effects of television in terms of changes in family behavior, political campaign styles, and rising expectations of the disadvantaged, as well as the primary impact on home entertainment. The potential applications of microcomputers are so diverse and pervasive that some social historians are suggesting that the inexpensive microcomputer may well rank as the *third major cultural invention* of the twentieth century, following the automobile and the television. If this is indeed the case, the side effects of microcomputers will truly be significant and far reaching.

From a societal viewpoint, the purpose of technology assessment is to develop policy options to enhance the positive and alleviate the negative side effects of technology. Thus, technology assessment is policy-oriented. This orientation stems from the milestone events that contributed to the establishment of technology assessments as legitimate and substantive programs within the realm of governmental activities in the United States. These milestone events were the proposal in the Daddario Bill to establish a Technology Assessment Board [3], and the formal establishment of the Office of Technology Assessment in the U.S. Congress [4]. In the executive branch of the federal government, the National Science Foundation, as well as a number of mission agencies, have sponsored over 100 technology assessment projects [5]. One of the larger completed projects is the Technology Assessment of Intercity Travel, cosponsored by the Department of Transportation and the National Aeronautics and Space Administration [6]. Microcomputers, an exploding technology developed only in the last few years, have not been the subject of a formal technology assessment prior to this effort.

1.2 TECHNOLOGY ASSESSMENT METHODOLOGY

Given its policy orientation, technology assessment itself is more a technology than a science, with all the implications of the difference between science and technology. Consequently, the philosophical and methodological approaches to technology assessment are multifarious [7].

A major taxonomy of technology assessment methodologies consists of the following three categories of technology assessment (TA):

1. Technology-driven TA.
2. Problem-driven TA.
3. Goal-driven TA.

In technology-driven TA, a particular technology (e.g., the automobile) is given, and its impacts on society are to be assessed. In problem-driven TA, a particular problem area (e.g., energy shortage) is given, and a range of technological options to alleviate the problem are to be assessed. In goal-driven TA, a particular social goal (e.g., increased job satisfaction) is given, and a range of technological packages to facilitate the goal realization are to be assessed. The current effort begins with the technology of microcomputers and asks what may be its impacts (on an organization or on society at large) and its policy implications (from the organizational or society viewpoint) between now and the year 2000. The study is thus primarily a *technology-driven* TA. Of course, no one can know for certain what will happen in the next two decades. However, it is important that the *plausible* impacts of microcomputers be assessed now, so that relevant decisions can be made in anticipation of, not in reaction to, the revolutionary developments of microcomputers.

A typical methodology for technology-driven TA is the following seven-step procedure [8]:

1. Define the assessment task.
2. Describe relevant technologies.
3. Develop state-of-society assumptions.
4. Identify impact areas.
5. Make preliminary impact analysis.
6. Identify possible action options.
7. Complete impact analysis.

This seven-step procedure has been used to guide this technology assessment of microcomputers and will be explained below.

STEP 1. TASK DEFINITION

As explained in the preface, special emphasis has been put on the impact of microcomputers on the national aviation system (NAS), although a broad assessment has also been made of the higher-order impacts of

microcomputers on society. Because of the rapid changes taking place in microcomputer technology, major emphasis is given to technology forecasting in this area, so that the actual assessment performed should be categorized as a "mini-TA" [9].

STEP 2. TECHNOLOGY DESCRIPTION

Chapters 2 to 7 describe today's microcomputer technology and project the development of the technology to the end of the twentieth century. To put the forecasts in a broader and more proper perspective, the forecasts of developments at the component (gate) level are combined into forecasts of microcomputer system characteristics for two typical application areas. These system forecasts require that attention be given to a variety of supporting components in addition to the microcomputer itself, including input/output (I/O) devices, sensors and packaging. These topics are reviewed in Chapter 4. A look at several technologies that support and/or compete with developments in aviation, ranging from satellite communications to high-speed ground transportation, can be found in a related publication [10]. The basis for the forecasts presented in this book includes the referenced literature, as well as interviews with a number of experts in the microcomputer industry.

STEP 3. STATE-OF-SOCIETY ASSUMPTIONS

Technology does not exist in a societal vacuum. Thus, forecasts should be conditioned by alternative sets of plausible assumptions about future socioeconomic constraints. The same constraints also provide the contexts for an assessment of potential microcomputer impacts on society. For this purpose, three alternative futures to the year 2000 [11] are used for this technology assessment. These three alternative futures are:

- Expansive growth.
- Resource allocation.
- Muddling through.

As will be discussed in Chapter 7, these alternative future scenarios represent, respectively, the upper, middle, and lower span of the spectrum of future activities in the United States.

STEP 4. IMPACT AREAS

If microcomputers are indeed as significant as the automobile and the television—and the initial indications are affirmative—their impact will