Harvard Business Review

ON

Managing High-Tech Industries

HARVARD BUSINESS SCHOOL PRESS

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MANAGING

HIGH-TECH INDUSTRIES

A HARVARD BUSINESS REVIEW PAPERBACK

Printed in the United States of America

03 02 01 00 99 5 4 3 2 1

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Library of Congress Cataloging-in-Publication Data
Harvard business review on managing high-tech industries.
p. cm. — (A Harvard business review paperback)
Contains articles previously published in the Harvard business review.
Includes index.
ISBN 1-57851-182-8 (alk. paper)
1. High technology industries—Management. I. Harvard business review. II. Series: Harvard business review paperback series.
HD62.37.H37 1999
620′.0068—dc21 99-18896
CIP

The paper used in this publication meets the requirements of the American National Standard for Permanence of Paper for Printed Library Materials Z39.49-1984.

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Turning Great Research into Great Products

MARCO IANSITI AND JONATHAN WEST

Executive Summary

IN MANY INDUSTRIES, superior technology integration—the approach used to choose and refine the technologies employed in a new product, process, or service—is the key to achieving superior R&D productivity and speed, and superior products. Access to great research is still immensely important, but if a company selects technologies that don't work well together, it can end up with a product that is hard to manufacture, is late getting to the market, and does not fulfill its envisioned purpose.

In this article, which is based on an ongoing study of R&D in various segments of the global computer industry, Marco Iansiti and Jonathan West contend that technology integration has become much more important—and challenging—for obvious reasons. The number of technologies from which companies can choose has

burgeoned. Both the breadth of technologies in a product or process and the potential sources of those technologies have increased considerably. Product life cycles have shortened dramatically, forcing companies to develop and commercialize new technologies faster than ever. As a result, the advantage now often goes to the companies most adept at choosing among the vast array of technologies and not necessarily to the companies that create them.

A radical change in the approach of U.S. companies to technology integration helps explain the resurgence of the U.S. electronics industry in the 1990s. But one size does not fit all. Indeed, the authors have found that an approach that works well in one country may not be the best for another. To be effective, an approach must suit the local culture and conditions.

IT'S LITTLE KNOWN, but one of the breakthroughs that led to the seemingly miraculous comeback of the U.S. electronics industry in the 1990s was the obscure process of technology integration. Business analysts often focus on the amount a company spends on R&D as an indicator of its competitive strength. But a company's process for rapidly and efficiently translating its R&D efforts into products that excel in satisfying the market's needs is much more important. After all, what a company gets for the money it spends on R&D is what ultimately matters. In many industries, superior technology integration is the key to achieving superior R&D productivity and speed—and superior products.

Technology integration is the approach that companies use to choose and refine the technologies employed in a new product, process, or service. Access to great research is still immensely important, but if a company selects technologies that don't work well together, it can end up with a product that is hard to manufacture, is late getting to market, and does not fulfill its envisioned purpose. An effective technology-integration process starts in the earliest phases of an R&D project and provides a road map for all design, engineering, and manufacturing activities. It defines the interaction between the world of research and the worlds of manufacturing and product application.

No company today can research every relevant discipline the way IBM and AT&T did during the 1970s and early 1980s.

Technology integration has always been important, but in the past ten years it has become much more important—and challenging—for obvious reasons. The number of technologies from which companies can choose has grown dramatically. Advances in chemistry, information technology, electronics, and materials science, for instance, mean that the technological bases of many industries are changing rapidly and unpredictably. In many industries, the breadth of technologies in a given product has increased dramatically, too. A computer workstation, for example, employs knowledge from almost every field of the physical sciences and mathematics—from the physics of nuclear decay, which is needed for the design of dynamic random-access memory (DRAM) chips, to the mathematics of graph theory, which is relevant to its software. No single company today can research every relevant discipline the way IBM and AT&T did during the heyday of the mainframe in the 1970s and early 1980s.

At the same time, the sources of new technology have also proliferated. Graduates from leading universities populate the R&D organizations of companies all over the world. Their expertise in science and technology has been fueling the growth of a wide range of suppliers around the globe that are familiar with the latest innovations. Any company can tap those sources, so all companies must constantly monitor the places that could spawn the next breakthroughs. If a market leader misses an important source or fails to spot a market gap, challengers will quickly seize the opportunity.

The advantage now often goes to the companies most adept at choosing technologies, not to the companies that create them.

To make life even tougher, product life cycles have shortened dramatically, forcing companies to develop and commercialize new technologies faster than ever. In the semiconductor industry, for example, product life cycles shrank by 25% in the 1980s alone. At the same time, uncertainty in the marketplace has soared. Consider the computer industry, in which market requirements change extremely rapidly and customers have a seemingly insatiable thirst for performance. By the mid-1990s, few could predict with any confidence how the Internet, the price of DRAM chips, or the emergence of Java as an Internet scripting language would shape customers' demands even six months into the future. As if all that complexity and uncertainty were not enough, computer companies also have to contend with a mindboggling array of standards and manufacturing processes.

The competitive game has changed: the advantage now often goes to the companies that are most adept at choosing among the vast number of technological options and not necessarily to the companies that create them. What's it like to compete in such a world? Consider the following examples.

Intel's newest chip-manufacturing facility cost close to $3.5 billion, most of which was for production equipment—a third of which had never been used before. That third included novel approaches to lithography, etching, and planarization, which would allow Intel to squeeze the width of circuits below the wavelength of light. The manufacturing process comprised more than 600 steps, all of which had to work together perfectly to achieve high production yields.

Microsoft faced an equally daunting task in creating its Windows 95 operating system. One targeted feature of the product was that users be able to "plug and play"—that is, attach any peripheral to their computers and have the system work perfectly. To achieve that goal, each of the technologies employed in Windows 95 would have to function seamlessly with an almost unimaginable number of hardware and software combinations. The operating system would have to include literally millions of instructions and a wide range of technological approaches. Microsoft and Intel both had to figure out how to start with a large number of technological possibilities, each of which could have an uncertain impact on a very complicated system, and quickly come up with a product that would work reliably and coherently.

Unilever faced a similar challenge in the early 1990s, when it set out to improve the performance of its laundry detergents in order to gain an advantage in its mature but highly competitive market. Its challenge: to find a combination of compounds that would substantially and visibly improve the quality of wash in, say, both Italy and England, where consumers' behavior and the characteristics of washing machines differ considerably. Unilever bet that manganese compounds would improve the performance of detergents. But how could the company make sure that the new compounds would work safely and effectively in all situations?

Creating novel technologies was not the biggest problem facing Intel, Microsoft, and Unilever. The companies' internal research organizations and external suppliers could provide many new possibilities. Nor was the development of products and production processes the major challenge. These well-oiled organizations boasted managerial processes that would ensure speedy implementation once the technological path was laid. The main challenge was choosing among the vast array of technologies.

In an ongoing study of R&D in various segments of the global computer industry, we have made some discoveries about technology integration that offer lessons for other industries buffeted by massive technological novelty and complexity.[1] One discovery is that the process of technology integration is critical to competitive performance. Indeed, changes in the process were a key reason for the resurgence of U.S. manufacturers of computers, electronic components, and software in the 1990s.

Each segment of the computer industry that we have been studying—mainframes, high-performance workstations, semiconductors, and software—has faced different challenges, such as the enormous capital investments needed for semiconductor production and the extreme uncertainty of the markets for workstations and multimedia. In each case, a company's ability to choose technologies wisely has had a large impact on the performance of its R&D organization in terms of time to market, productivity, and product quality. In large mainframe projects, for example, differences in technology integration processes explained variations of as much as a factor of three in R&D productivity; at some companies, weak technology-integration processes caused delays of several years in developing new products. In workstations, companies with excellent technology-integration processes brought new products to market as much as two times faster than did competitors with less effective processes.

A company's approach to technology integration must fit its capabilities and local culture.

Our data suggest that differences in the technology integration process are more important than disparities in project management methods, leadership qualities, and organizational structure in explaining variations in performance. There are two reasons for this phenomenon. The first is that many of the most effective ways of organizing and managing projects have already been adopted throughout the world in this fast-moving industry. The second is that if an organization chooses the wrong technologies, the project will run into problems regardless of any other factor.

Another important discovery about technology integration is that there is not just one successful approach. Rather, to be successful, the approach adopted must be in harmony with a company's capabilities and its local culture and conditions. Our research in the semiconductor industry documents these ideas in detail. But before we delve into the evidence, let us explore how technology integration works.

A New Approach to R&D

In 1990, even the mightiest U.S. players in the computer industry were in retreat, and a lot of the weaker players had disappeared. IBM had lost substantial market share to Japanese manufacturers in every hardware segment. Intel was consistently late in introducing new generations of semiconductor technology and new chip designs. And even Microsoft's competitive position in software seemed in jeopardy as a result of severe delays in introducing new products as well as problems with product reliability.

A scant five years later, however, the U.S. industry had regained lost ground in such critical segments as semiconductors, personal computers, workstations, servers, and laptops. Intel and Microsoft had consolidated their leadership in microprocessors and software, respectively. IBM had improved its development and manufacturing capabilities and had introduced a wide variety of impressive new products. And a fresh generation of start-ups such as Netscape and Yahoo! had staked out the latest growth segments: Internet software and services.

In retrospect, it's clear that haphazard technology integration never worked well.

The resurgence of the U.S. companies was rooted in a new approach to R&D. During the 1960s and 1970s, U.S. companies such as IBM, Xerox, and AT&T succeeded by making breakthrough discoveries in their R&D laboratories and then turning those inventions into breakthrough products. The names of their R&D operations—the Thomas J. Watson Research Center, the Palo Alto Research Center, and Bell Laboratories—became synonymous with U.S. innovativeness.

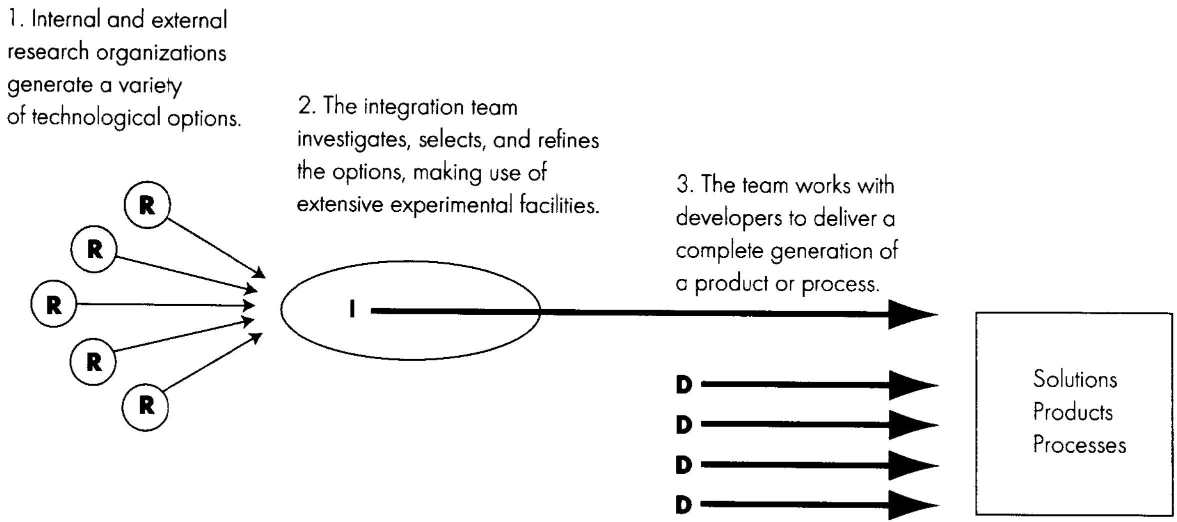
Technology integration, such as it was, occurred in the following manner: isolated research groups would explore new technologies and choose which ones the development organization would use; the development organization would refine them; and the new product or process would then be passed on to a manufacturing organization, which would remove the bugs. Because there was no process for taking a view of the entire project when choosing technologies, many of the choices were poor. That outcome is not surprising, considering the traditional roles of scientific research (exploring the potential of narrowly defined technological possibilities) and of development (turning a specified set of technologies into detailed designs and manufacturing processes).

In retrospect, it is clear that this haphazard approach to technology integration never worked well. But its shortcomings did not become glaringly apparent until the competitive landscape changed during the 1980s. Mere tinkering wouldn't suffice. U.S. computer companies needed something new to bridge the gap between research and development—to turn outstanding research into outstanding products and processes. Traditional industrial labs could not fill the role. They had been developed to shield research organizations from day-to-day business pressures so that researchers could focus on creating or discovering important technological concepts.

The U.S. companies that prevailed in the computer industry in the 1990s abandoned the traditional R&D

model and created a radically new one. They did not stop conducting basic research, but they did shift much of the focus of their research efforts to applied science, and they turned to an increasingly diverse base of suppliers and partners—universities, consortia, and other companies—to help generate technological possibilities. In addition, they formed tightly knit teams of expert integrators—people with extensive backgrounds in research, development, and manufacturing—to develop new generations of major products and processes. Those integrators were given various titles—process integrators at Intel, program managers at Microsoft—but they all carried out similar functions. Companies charged the integration teams to take a broad, systemwide outlook and gave them considerable freedom in conceptualizing the new generation and choosing its technologies. The aim was for the teams to create a concept of the future product that would fit customers' requirements and could be manufactured rapidly and efficiently. They were thus given overall responsibility for developing the concept, and they worked closely with developers to deliver a perfected product and production process to manufacturing. Developers and, in many instances, suppliers had responsibility for individual components, but the integration team retained responsibility for the whole project. In addition, companies gave the integration teams enormous resources for testing a wide range of technological possibilities. The result was an approach to technology integration that excelled in finding important new technologies that provided extremely successful solutions and in finding them very quickly and efficiently. (See the exhibit "The Emergent Model of R&D in the U.S. Computer Industry.")

The Emergent Model of R&D in the U.S. Computer Industry



The approach took advantage of local conditions, such as the employee churn that had become a way of life in many U.S. industries. It exploited the country's wealth of top-notch research universities and the ready supply of people with graduate degrees that they produced. Instead of keeping teams intact from project to project, the companies refreshed them for each new generation of a product or process by bringing in people who were conducting cutting-edge research at universities and other businesses.

This model would be difficult to deploy in Japan. Because the country has a much weaker tradition of university research, Japanese companies cannot access the rapidly evolving base of fundamental knowledge in science and engineering through universities the way U.S. companies can. And because long-term employment—at least at large companies—is the norm, Japanese companies cannot obtain knowledge by luring away competitors' employees. They must develop most of their fundamental knowledge internally or obtain it from suppliers or alliances with U.S. companies. But Japanese companies do enjoy certain advantages: close links with suppliers, strong cross-functional relationships among employees, and a wealth of employees who have been involved in creating several generations of a product or process.

Japanese integrators tend to favor incremental improvements or refinements of familiar technologies.

To choose which technologies to employ, Japanese companies rely on a network of veteran employees—few of whom have Ph.D.'s—who work in a variety of functions. A loosely structured group of about a dozen people usually coordinates the effort, but its role does