DOCUMENT RESUME

ED 328 777 CE 056 993

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TITLE The Employment Effects of High-Technology: A Case Study of Machine Vision. Research Report No. 86-19.
INSTITUTION National Commission for Employment Policy (DOL), Washington, D.C.
PUB DATE May 86
NOTE 53p.
PUB TYPE Reports - Research/Tech:.cal (143)

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS Adults; Artificial Intelligence; *Computer Oriented Programs; *Economic Development; *Electronics; Employment Projections; *Futures (of Society); Labor Market; Labor Needs; Manufacturing Industry; *Robotics; *Technological Advancement
IDENTIFIERS *Machine Vision

ABSTRACT

A case study of machine vision was conducted to identify and analyze the employment effects of high technology in general. (Machine vision is the automatic acquisition and analysis of an image to obtain desired information for use in controlling an industrial activity, such as the visual sensor system that gives eyes to a robot.) Machine vision as a new industry has taken off on an exponential rise. The total employment in the machine vision industry has been growing rapidly and will continue to increase. A large portion of the jobs have been taken by highly trained technical people. However, as the process becomes more standardized, blue-collar workers with additional training will be able to fill some of the jobs. The United States leads the world in the development of machine vision. It is expected that this industry may help lessen the number of imports coming into the United States and the amount of labor-intensive manufacturing leaving the country. The near-term prospects for the machine vision industry require the identification of markets with sufficient volume of applications and a process technology to produce the vision systems at a low enough cost to attract users and generate profits in the industry. (15 references) (KC)

THE EMPLOYMENT EFFECTS OF HIGH-TECHNOLOGY: A CASE STUDY OF MACHINE VISION

by

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May 1986 RR-86-19

RESEARCH REPORT SERIES
NATIONAL COMMISSION
FOR EMPLOYMENT POLICY
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The conclusions and recommendations in this report are those of the contractor and do not necessarily reflect the views of the National Commission for Employment Policy or any other agency of the Federal Government.

TABLE OF CONTENTS

PREFACE

The National Commission for Employment Policy has for the past two years been studying the effects of computers on employment and training. The Commission's policy statement and recommendations, accompanied by a staff report, were recently published in Computers in the Workplace: Selected Issues. The present paper is the last of a series of research reports published as part of this project. The paper is also among the first in a series of reports to be published in connection with the Commission's current work on the internationalization of the United States economy.

Technological change and international competition are having pervasive and interactive effects on the markets for American goods and services and for American workers. Professors Chen and Stafford have conducted a study of a firm and industry in which these forces are particularly evident. Insights from this report will contribute to the discussions of technology and trade issues which have become central to economic policymaking.

This report is unusual for employment policy research because it represents a collaboration between an engineer (Chen) and an economist (Stafford). The analysis is especially valuable because it integrates the technological possibilities of machine vision with the very real economic constraints facing an emerging industry. The Commission expresses its appreciation to the authors for their thoughtful work.

The series of Commission-sponsored reports on computers in the workplace was designed by the Commission project staff: Carol Jusenius Romero, team leader; Sara B. Toye and Stephen E. Baldwin, under the general supervison of a Commission work group chaired by Commissioner D. Quinn Mills. This team worked closely with the authors in organizing this study; however, the information presented and the conclusions drawn do not necessarily reflect the views of the Commission or its staff.

EXECUTIVE SUMMARY

A case study of machine visison has been conducted to help identify and analyze the employment effects of high technology in general. Machine vision is the automatic acquisition and analysis of an image to obtain desired information for use in controlling an industrial activity. Examples include the visual sensor system that gives eyes to a robot , and the automatic optical inspection of silicon microelectronic chips at the levels of speed and reliability beyond human capability.

After some years of research and development, machine vision as a new industry has taken off on an exponential rise. The major users are presently concentrated in the automotive and electronics industries, with rapid growth and diversifications in aerospace, food processing, and other industries as well. In the next 5 years, sales are likely to grow by a factor of 5 or more over the present volume of about $125M per year. This rapid growth will be accompanied by greater use of standardization, stronger linkage between machine vision and integrated manufacturing systems, and substantial diversification of applications. At present, most of the 125 machine vision firms with annual sales over half-million dollars are relatively new, small, and independent; and very few of them are profitable. A shakeout is expected to narrow the field down to the order of 25 survivors in 5 years.

The total employment in the machine vision industry has been growing rapidly in proportion to its sales, at about one employee per $50,000 annual sales, and now stands at about 2,500. As the industry strives to become profitable, the ratio is likely to approach that for the high-technology industry in general, or one employee per $100,000 annual sales, so that jobs will grow less rapidly than sales.

A large portion of the jobs have been taken by highly trained technical people, and even the nontechnical positions such as marketing and administration are frequently filled by people who have some technical background or have been in non-technical positions with other high-technology industries. These professionals spend a significant portion of their time to get further training. Very few blue collar workers (less than 13 percent of total employment) are in the vision industry at present. Support personnel, mostly white collar workers, are generally young and highly motivated with prior training in computerized office skills.

Most employees the vision industry have come from other high technology firms or relatively high growth industries, or directly from schools. In general, they are more satisfied, or at least equally satisfied, with their present jobs than their previous jobs. They feel confident about their future career growth with the whole machine vision industry even when their own companies may be under financial difficulties. Those in the industry report a much closer social network among their coworkers than they experienced in larger, more established firms.

While employment in the vision industry has grown rapidly, the user firms, on the other hand, have had a reduction of work force on the factory floor due to machine vision applications. However, those who remain on the job get upgraded. Many of the current user applications employ engineers. With the trend toward standardization of machine vision products, more blue collar workers with proper training will be able to operate the new technological systems. As machine vision is an important and integral part of the flexible manufacturing systems of the future, its indirect employment effect on the reduced needs for the large number of tool and die makers in support of the traditional manufacturing systems may be even more significant.

The U.S. clearly enjoys a leadership position in machine vision at present. It is expected that foreign competition, especially from Japan, will be significant in the next 10 years. However, the foreign competitors, it is believed, will gain market share mostly in hardware and standardized components of the machine vision systems. U.S. firms are expected to continue leadership in software and total system applications. Joint ventures between U.S. and foreign firms will accelerate technology exchange and mutual access to each other's markets. Our research indicates some difference of opinion on the issue of international competition: upper level people in the vision firms anticipate a smaller extent of import penetration than is expected by those in the sample of the Automated Vision Association survey.

It is interesting that some people see the impact of machine vision as possibly bringing some of the offshore manufacturing activities, especially in electronics, back to the U.S. Most people at least agree that machine vision may help slow down the offshore migration of labor-intensive manufacturing, if not actually reverse the trend. Our research suggests that machine vision has definitely helped this trend in the production of customized products, and may help also in the production of commodity products indirectly through the application of machine vision in flexible manufacturing. However, there are many attractive factors keeping electronics plants overseas, where a manufacturing infrastructure for the U.S. firms has built up since the late 1960s.

The near-term prospects for the vision industry require the identification of markets with sufficient volume of applications and a process technology (presumably using flexible manufactruing and vision systems) to produce the vision systems at a low enough cost to attract users and generate profits in the vision industry. The practical business side of the industry has not yet developed sufficiently and brings the risk of a much slower adoption of this technology. Without positive cash flow the companies in the industry will be unable to continue their work on developing new products. Thus, there is a need for a breakthrough to profitability by vision industry's firms as part of broadened markets to sustain technological change in the industry.

THE EMPLOYMENT EFFECTS OF HIGH-TECHNOLOGY: A CASE STUDY OF MACHINE VISION

I. INTRODUCTION

Background

Rapid technological changes and imbalance of international trade have been considered as two major causes of employment problems in the United States. In response to these concerns, the National Commission for Employment Policy (NCEP) has been investigating technology and trade. This paper is a part of that investigation.

In contrast to the picture of job loss in our export competing sectors, the rate of job creation in the U.S. in recent years has been outstanding among the industrialized nations. While many of the new jobs are in the service sector and require relatively low skills, rapid technological change has also contributed to job creation, especially in new, growing, small and medium-sized high-technology firms. Yet no systematic micro-level studies have been made of the quality and quantity of such positive employment impacts of technology.

It will be valuable for policy makers to have a clearer picture of the nature and extent of the employment impacts of high technology industries. What is the rate of job creation in this area? Where do the new employees come from? Are they happier in the new jobs than in their previous jobs? What are the required qualifications for their new jobs? What training programs exist for such people to acquire, maintain, and improve their job qualifications? Are these training programs provided by the companies or by outside educational institutions?

There are also questions regarding international competitivenes and trade in the high technology area. Does the United States really enjoy a dominant position in this area? Are there early warning signals of stiffening international competition, with accompanying job impacts? What employment implications are there as we consider trade policy in this area?

Case Study

As a step toward developing a better understanding of the employment effects of high technology industries, the present case study was initiated in September 1985 under the sponsorship of NCEP, using a methodology developed previously by the U.S. Department of Labor's Bureau of International Labor Affairs to assess the impact of automation technologies on employment (Chen, 1985). The industry chosen for the study is machine vision. Machine vision is the automatic acquisition and analysis of an image to obtain desired information for use in controlling an industrial activity. A typical example of machine vision is the visual sensor system that gives eyes to a robot. Other applications include image processing for space satellites and automatic inspection for quality control. An engineer in the auto industry has recently described the vision controlled system used to install windshields in autos as the most sophisticated current application of industrial robots. As we will see in Section II, such three-dimensional (3-D) robot guidance systems embrace elements of four different underlying vision application technologies (Figure 1). Because of its novelty in industrial applications and relatively sophisticated technology, machine vision is currently "the high tech among high techs for automation".

There are 125 U.S. vision firms with yearly sales over $500,000, and perhaps 50 such firms in other countries (see Appendix A for source). Some of the early vision firms were spawned by the Environmental Research Institute of Michigan (formerly the Willow Run Laboratories of the University of Michigan). Others were offshoots of other universities and research institutes; e.g., Machine Intelligence Inc. was an offshoot of SRI International (formerly Stanford Research Institute). One of the early major industrial end users of machine vision has been automobile companies. Integrated circuit manufacturers were also very early users of vision. For historical reasons, as well as because the auto industry is a large market for the application of vision systems, a fairly large portion of U.S. vision companies are in Southeastern Michigan; Ann Arbor claims to be the center of "vision valley". However, there appears to be a recent growth in the application of vision systems in electronics manufacturing which may lead to greater geographical dispersion of the vision industry to the West and East Coasts.

The present case study is focused on Machine Vision International (MVI), a company that took the name of the industry. There are a number of reasons for the case study to focus on MVI: (1) its technical leadership in the field of machine vision; (2) the diverse technology base for its products which range from industrial to defense applications, and from mechanical to electronic components inspection; (3) its broad scope of services that are typical of vision firms, including R&D, engineering, marketing, purchasing, production, training, publication, and customer services; (4) its rapid sales growth, from $1/2 million the first year (1983) to $4 million the second year, to over $9 million for the third year; (5) its employment growth, from just a few workers in the first year to 110 the second year, to 159 at the end of the third year (1985); (6) its international connections, beginning with an early project for Seiko in Japan; and (7) most importantly, its willingness to participate in the case study.

<u>Work Completed</u>

Three kinds of work have been conducted in this case study:

(1) literature review, (2) discussions with MVI's employees, and a number of its suppliers, customers and peers, and (3) reflection and analysis. Appendix A shows a list of documents which have been reviewed. Most of the documents have been provided by MVI. Important information has also been obtained from other interviewees and from the University of Michigan which conducted a Delphi marketing and technology survey for the Automated Vision Association (Heytler and Smith, 1986).

Discussions were first held with about 40 employees at MVI, including a cross section of high-level executives, technical personnel, nontechnical professionals, technicians, and support personnel. Many of their responses were based on a stylized picture of the industry which we had developed as shown in Appendix B.

Our contacts then expanded to include meetings and discussions with suppliers, users and other firms in the industry. Some of the firms turned out to be both suppliers and users of machine vision. To illustrate, one firm, Intel, is an important supplier to the vision system manufacturers as well as being a demander of vision systems in their own production process. In this example we can see a full circle of the vision industry as a demander of inputs from suppliers as well as a means by which manufacturers can improve their productivity and quality of their process technology.

To obtain first-hand observations of how direct labor is used in the vision industry, we visited the production operations of three machine vision manufacturers: MVI, Automatix, and GMF. Visits were also made to the production lines of automobile, microelectronics, and telecommunications firms which use machine vision, in order to see first-hand some of the employment effects of the machine vision technology on its user industries. We also reviewed the key elements in recruiting, compensation and production scheduling in these firms. Reflection and analysis on the basis of the gathered information, with an emphasis on employment implications, were then conducted by both principal investigators representing the disciplines of engineering and economics.

The remainder of this report will present our findings in five sections: (1) the characteristics of the machine vision industry, (2) the employment characteristics within the vision industry, (3) the impacts on the two major user industries (autos and electronics), (4) international competition -- not only in terms of international competition within the vision industry but also how vision affects the international operations of the microelectronics industry, which is both a user and a supplier of the vision industry, and (5) conclusions and implications for policy.

II. INDUSTRY CHARACTERISTICS

This section will discuss the characteristics of the emerging industry of machine vision, with a special emphasis on the rates of change of sales, employment, and technology.

A "Young" Industry

Survey data have indicated an exponential growth of machine vision from 1982 to 1986, with total sales and number of systems shipped doubling every year. The figures stand at about $125 million and 2,500 systems shipped in 1985, averaging $50,000 per system. Note that some of these average-sized systems are often combined and sold as much larger systems. Accurate data for the whole industry are difficult to obtain because (1) there are no clearly defined boundaries of vision systems, (2) many small vision companies are privately owned, and (3) the large vendors such as GE, IBM, GMF Robotics, and Kodak do not reveal sales figures for their vision business. The employment data from MVI, Automatix, and other vision firms suggest that the number of employees is roughly proportional to sales and to the number of systems shipped. At the ratio of 1 employee per system shipped per year, or 1 employee per $50,000 per year sale, the total employment in the machine vision industry is about 2,500, having grown at the rate of about 100 percent per year.

Growth Pains of the Industry

The burgeoning industry of machine vision has its share of growing pains. While new advances in the technology are made in the laboratory at a rapid rate, the practical and diverse applications in the factory are not easy to implement. Many of the technical people we have interviewed say that nine out of ten applications are struggles to make the technology work in the factory environment.

This can be illustrated with vision systems for paint inspection. In developing vision systems for paint inspection in automobiles practical problems include variability in the actual paint provided to automobile companies. Prior requirements for paint had standards for color variations, durability, gloss, and so on. However, two paints that meet the same specifications according to these requirments may not be inspectable by the same vision system because machine vision can tell differences in previously unspecified requirements; e.g., paint texture. To remedy the problem of supplier variations in paint, the using company may find itself in the position of requiring that the final painted products be "inspectable" by a vision system as a new criterion for defining an acceptable supplier. This forces the supplier to get involved with complex issues of vision technology in order to supply paint! For these kinds of reasons paint inspection, which should be a large and profitable area for vision applications, remains an area with not-yet-resolved problems of implementation.

As the large number of relatively small firms (125 firms in the U.S. with annual sales of at least a half-million dollars) vie for market share, only very few (probably no more than 10 percent) are profitable at present. The profitable ones, such as KLA Instruments and View Engineering, appear to focus on simple technology and a simple and narrow range of applications.

The average ratio of one employee per $50,000 annual sales in the machine vision industry given previously is a strong indicator of the industry's profitability, or the lack of it. Because the cost per employee in this industry averages $40,000 per year, the revenue of the machine vision industry at this point can barely cover the salaries and benefits of its total employment. Like other high-technology industries at this early phase of development, machine vision firms appear to need a ratio of at least one employee per $100,000 annual sales to make respectable profits. In the robotics industry several years ago the per employee sales figure needed to attain profitability was estimated to be $90,000, (estimated by H. Allan Hunt of the W.E. Upjohn Institute for Employment Research, Kalamazoo, Michigan). GMF Robotics, the undisputed leader in robotics, has a ratio of over $300,000. Even though the breakeven ratio for machine vision is expected to be lower than robotics as less hardware is involved in vision, the current ratio of $40,000 is obviously unprofitable. Thus some of the vision firms have gone through a hiring freeze and have even contracted employment after a temporary overexpansion, although the total employment in the industry has continued to grow. The 100 percent growth rate of the industry in the past few years is not expected to be sustained. Most knowledgeable people we have talked to in the vision industry expect a 40 to 60 percent growth rate in sales for the next five years, and a lower growth rate for total employment.

Prospect for the Future

In spite of these growing pains, optimism about the future of the vision industry is widespread among all employees in the industry, regardless of whether they are executives, technical employees, nontechnical professionals, technicians or support people. They also believe that vision is going to help increase quality and productivity of U.S. manufacturing, and therefore U.S. international competitiveness.

In addition to the 125 U.S. firms with annual sales over 1/2 million dollars in vision products, there are probably 50 other such vision firms around the world. The rate of firms coming into the industry has slowed down. The industrial dynamics and the profit situation are such that the cost of entry into the industry is believed to have increased from about $20 million a few years ago to $40 or 50 million today. While a shakedown to some 25 survivors may be expected within 5 years, employment growth is asured as long as demand and sales volume continue to rise.

The pattern of machine vision industry development is consistent with what is expected of a growing industry. The learning effects and dynamic cost structures of a growing industry are such that current production builds experience capital which, in turn, lowers future production costs. Under these conditions firms have incentives to price below cost in the current period as long as the industry continues to grow, and future profitability can be more probable for firms producing some of the more standardized vision products in the future. During the transition period to profitability there is great uncertainty facing the financial backers as well as the employees of the firms. Many of the firms in the industry appear to have a disproportionate representation of young people. This suggests that when some of the firms either contract after overexpansion or drop out of the competition, the costs of mobility among the workers would not be as great as if the firms employed older workers, who are known to experience higher costs of relocating.

Because of the diversity of applications, it seems probable that even as the industry matures and stabilizes, much of the work activity would be customized. From the perspective of workplace organization this raises questions about the likely size and the organizational structure of the eventually surviving firms.

There are two reasons why small or horizontally structured large firms (which have smaller organizational units than vertically structured firms) may be common among the surviving firms. First, smaller firms or units may be better suited to rapid organizational change as new product opportunities arise. Second, the customized products which many vision firms will have to continue producing make it difficult for the large unit to monitor the efforts of different people in the unit. This is because with a large unit or firm it may be more difficult to ascertain individual workers' efforts and to maintain incentives for workers on customized projects that have no standardized measures of cost and product success.

It is also possible that the larger firms with horizontal organizational structure may "fission" wherein new firms start up from groups of employees within the existing firms. On the other hand, large firms, or small firms with financial backing from large corporations, have "deeper pockets" to sustain a longer period of unprofitable growth and thus a higher survivability during the anticipated shakeout. The fortunate survivors are therefore likely to be those firms that are not only technically competent but organizationally geared to individual innovation and strong financial backing.

Continuing Technological Change

Within a young and growing high tech industry, machine vision technology is expected to go rapidly through further development. The presently dominant 2-dimensional binary (black and white) vision technology is being replaced by 2-dimensional grey-scale technology in many applications, and 3-dimensional vision technology is already on the market.

Two technological frontiers are being pushed to help increase the capability of machine vision. One is the logical algorithm, occasionally helped by artificial intelligence, that permits the system to achieve color, 3-D, dynamic perception and to take intelligent actions accordingly. The other is the speed of image processing, using logic gates with shorter and shorter propagation delays, which typically have decreased from 2.5 nanoseconds (10^{-9} seconds) to 1.5 nanoseconds in the last few years, and are approaching 700 picoseconds (10^{-12} seconds) in the foreseeable future.

It is expected that business environment in the machine vision industry will be at least as mercurial as that in the robotics industry. In robotics we have seen a dramatic reordering of industry leadership as the newly-formed GMF Robotics has replaced Cincinnati Milacron as the industry sales leader. One reason for expecting substantial fluctuations in the fortunes of individual machine vision companies is the diverse technical base of the industry. As has been argued by Sternberg (1985), two of the key dimensions underlying computer vision technology are first whether the system is image based or object based, and second whether computations are arithmetic or logical. This two-by-two categorization created four underlying technologies, each of which has different methods and industrial applications. (See Figure 1 in the next page.) As Sternberg further points out, many of the companies are positioned in a single technology cell in this matrix. What this implies is that future developments in particular application areas may lead to rapid growth or contraction of particular technology cells with corresponding financial and employment fluctuations for the companies within them. On the other hand, if a firm attempts to embrace too broad a range of technologies it may not focus on a few profitable segments and may have difficulty surviving financially.

The Role of Standardization and Compatibility

In addition to linking the various production activities together via systems such as the Manufacturing Assembly Protocol (MAP), there is an effort underway in both the United States and Europe to achieve compatibility between the manufacturing information systems and office information systems (MAP/TOP, the latter standing for Technical Office Protocol). This would permit a coherent unification of such activities as sales, purchasing, manufacturing and accounting. The additional challenge is that the product offerings of manufacturing are to be increased in diversity so that coordination of the various components represents a far greater accomplishment than would be the case if only a few standard products were involved. This overall transition may have dramatic implications for both office

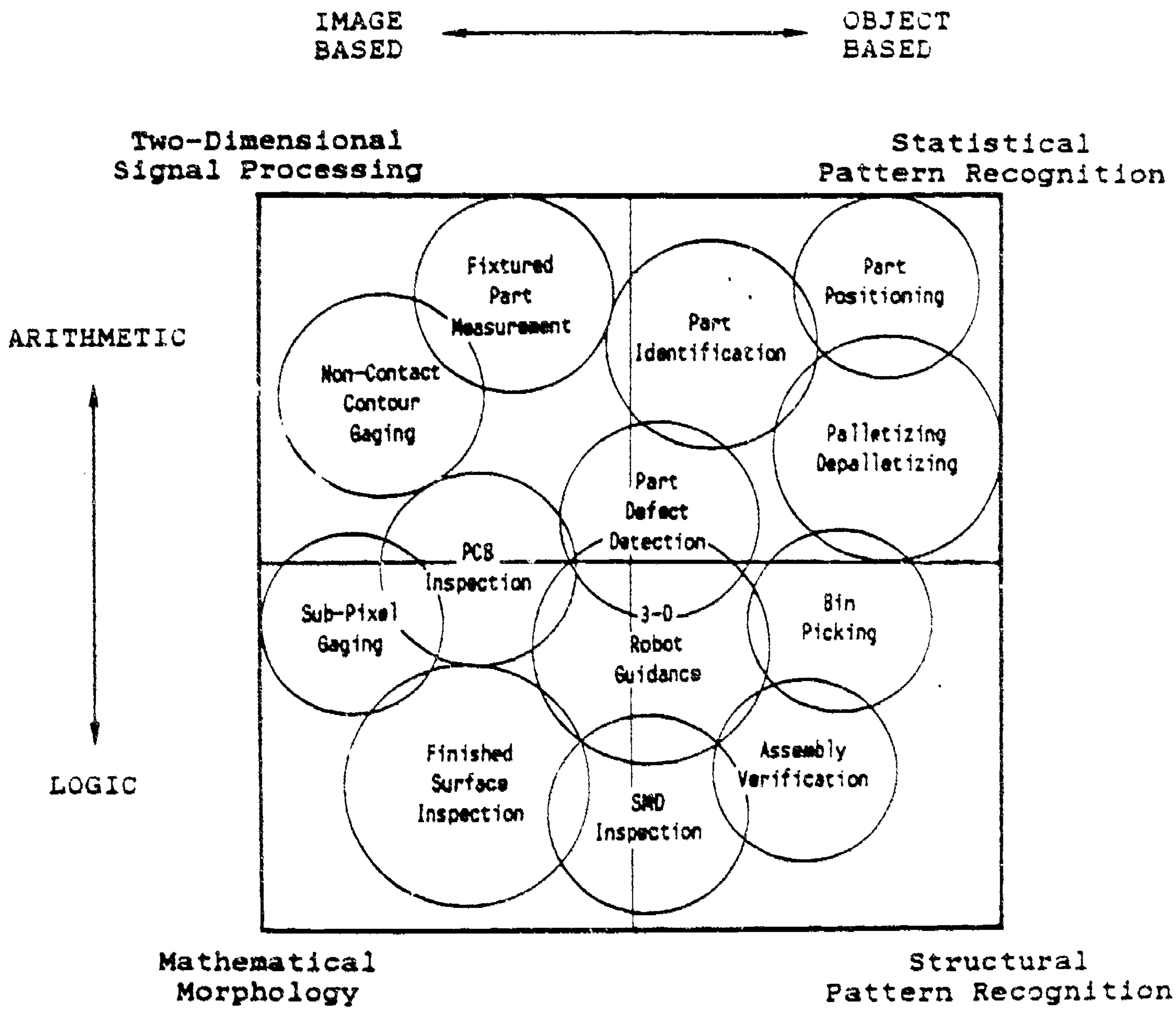


FIGURE 1

MACHINE VISION APPLICATIONS:
MATCHING REQUIREMENTS TO TECHNOLOGY

and manufactruing employment and at various levels within an organization. At this point we do not feel that we have a sufficient understanding to indicate an obvious outcome from all of this. Yet it does seem that the range of effects could be very broad and could affect numerous smaller suppliers and their employees since one of the purposes of a system like MAP is to allow informational linkages to suppliers and subsuppliers.

The capability of high-tech computerized products to communicate or "talk" to each other in an integrated system cannot be overemphasized. Industry pundits ascribed the recent profit downturns of such companies as Computervision (a firm with insignificant products in machine vision in spite of its name but a leading firm in computer aided design systems) and Apple Computers (a leading firm in microcomputers) to the relative difficulties in tying Computervision's diverse products together in a mutually compatible way, and to the incompatibility between Apple and IBM computers.

Geographic Patterns of Growth

So far there has been a substantial geographic concentration of the industry in the "Vision Valleys" surrounding Ann Arbor, Palo Alto, and Boston. This geographic concentration has been relatively stable, and rapid growth of applications in the electronics industry could lead to some additional geographic centers of activity on the West Coast and the East Coast. The strong geographic concentrations seem to rest on a network of competing firms with personnel migration across firms as well as interrelations among suppliers and users in the vision industry. As in other technology based industries, the role of universities is apparent. The personnel in the industry are highly trainied. A large proportion of the employees in the industry are engineers, and a continual flow of new ideas from the university environment appears critical for the vitality of the industry. Only after the industry's technology becomes stabilized and the industry itself becomes profitable will geographical decentralization be possible. There is little doubt that high tech industries' direct positive impacts on employment are shared very unevenly among the different parts of the country.

III. EMPLOYMENT CHARACTERISTICS

This section will discuss the characteristics of employment in the machine vision industry. The findings are based primarily on the discussions with a wide range of employees within the vision firms which we have visited. The employment effects of vision in the user industries will be discussed in Section IV.

Employment Composition

As a "high tech among high techs", the machine vision industry has a very high proportion of technically trained people; it borders on being an R&D segment of the automation industry. A new small vision firm would have a few specialists in vision, assisted by a good number of scientists and engineers. The nontechnical positions such as marketing are likely to be filled with people who are conversant with technical people both within the vision firm and in their customers' companies, and who may be degreed engineers themselves. Sometimes it is difficult to tell the difference between a marketing manager and an application engineer within the vision firm. The executives would include people who are experienced in starting up high tech firms -- know how to raise venture capital, assemble a management team, anticipate growing problems, market highly sophisticated technology, and manage technical personnel. The support personnel, though without technical background in machine vision or related technologies, are likely to be young, flexible in their attitudes toward work assignments, and skilled in operating automated office equipment.

Job Satisfaction

Most employees in the vision industry, in all categories of jobs, find their current jobs exciting and generally more satisfying than their previous jobs outside the industry. They feel that what they are learning from their jobs now is portable and useful in other firms, and has put them in a better position to look for other jobs if the need should arise in the future. Those in the industry report a much closer social network among their coworkers than they experienced in larger, more established units or firms. With constant technological change and frequent turnover or occasional contraction of employment in individual firms, some employees have experienced periods of high stress and anxiety. However, being in the rapidly growing business environment, all employees in the industry generally feel that there is plenty of room for them to grow together and there is no need to compete with one another for diminishing resources or for narrowing opportunities internally, at least in the industry as a whole.

Another reason for close interaction among coworkers, extending beyond the workplace, was apparently the need for effective monitoring of work effort and enforcing directions. Many of the critical tasks in the company are hard to define and evaluate, yet overall success of the company will depend on the joint effort of many of its people. Extensive social i teraction has provided an avenue for improved assessment of each person's effort and contribution to company goals. Large firms with fairly stationary environments develop personnel practices to evaluate performance contributions by individuals. In small, rapidly changing organizations such formal procedures would be too cumbersome and off-target. Teamwork is achieved by mutual knowledge of one another's contribution and reinforcement (by status or compensation) of activities that are regarded by the group as more valuable in achieving shared goals. Mechanisms such as employee stock ownership plans have serious incentive limitations because even in a relatively small firm, efforts by any individual, insofar as they contribute to company profitability, would also create benefits for all the others with equity interests.

Matching between Jobs and Employees

Since the new and rapidly growing vision firms are able to recruit from scratch, the match between the required qualifications and the recruits' educational backgrounds and/or work experiences is exceedingly good. This close match may not hold up as the companies expand and existing employees without the closely matched qualifications are assigned to the new jobs. Further, if educational and training processes do not adapt quickly to the demand, which is growing but also uncertain, there may well be a shortage of people with the required formal training and experience who can be drawn upon outside the firms.

Continuing Education

Increasing technological sophistication has compelled the leading vision firms to hire the most recent gradutes, and some of the research faculty at the forefront of the technology, from a few top-notch universities. Some have claimed that tne "half-life" of the technically trained people in these firms is getting shorter, no more than 3 to 5 years. In one supplier firm the manager and his associates stated that over 40 percent of each workweek is devoted to learning new skills and acquiring information about new products or having seminars to present new applications to potential buyers. Some companies have developed special training centers or "mini-campuses" within their organizations. GMF has trained about 6,500 people as part of their contracts to supply robotics and vision systems. On the other hand, some have argued that the new skills learned are mainly applied in nature and the information given in the seminars is mostly company-specific, and that the basic skills of individuals with the right educational background are more durable and essential than suggested by the above estimates. Another perspective is that some technical training in basic skills provides the basis for acquiring new knowledge and skills on the job.

This rapid change in required job knowledge is expected to continue and will lead to efforts to retain those workers who have acquired special training on the job, and also to put increasing pressure on the firms to retrain and upgrade their technical people one way or another. This creates some resource difficulties for the firms. Training takes time and reduces short-run output. It also leads to skills which are "general" in the sense that they can be used by other vision (and nonvision) firms. This raises questions about the nature of incentives which firms can offer to retain their key skilled personnel. Several managers in a supplier firm indicated that employees are required to agree to stay with the firm for a specified length of time in order to receive training in particular product lines.

Small Production Workforce

The "production line" in a typical leading vision firm has very few blue collar workers. Of the total employment at MVI of over 150, only 19, or less than 13 percent, are in the production department. Of the 19 in the production department, 9 are technicians. Thus direct labor accounts for only 6 percent of the total employment at MVI. This percentage is not expected to increase, and may actually decrease, as the sales volume increases in the future. Other vision firms are in a similar situation. For example, only 10 percent of the employees in Machine Intelligence Inc. are in production. Automatix, a robotics and machine vision firm established in 1980, has a total employment of 290, with an estimated annual sales of $7 million attributed to machine vision (out of a total of $27 million in 1985, the remainder being robotics and systems sales). About 45 percent of the employees of the whole company are in engineering, 20 percent in marketing, 7 percent in general support, and the rest, or 28 percent, in manufacturing. Of the approximately 80 people in manufacturing, there are about 37 technicians, including field service people. Thus direct manufacturing labor accounts for less than 13 percent of the total employment, and the percentage is probably lower for the vision part of the business. This pattern of very low direct labor is also present in the robotics industry.

Direct labor is a small fraction of the employment in vision firms in part because the supplier network in the industry is such that many of the required components can be built via subcontracts. Much of the work in the production department is related to assuring the quality and reliability of product components. The production workers hired are all experienced, typically having worked with electronic components at the chip level. They all have associate degrees, for the most part from local community colleges. Only one of the production employees at MVI is a retrained auto worker. A major barrier to employment of those previously in the auto industry is the fact that their wages are substantially higher (15-30 percent) and they are often reluctant to adjust to a lower level of income. This barrier is more important than the educational backgrounds or work skills of the auto workers. At Automatix, several technicians had worked in mature electronics firms in the Boston area (such as Raytheon and

Honeywell) before they were hired, and wage levels in the electronics and vision firms are comparable.

Because production is such a small part of overall employment costs, vision firms can be located in a relatively high wage area -- such as Michigan and Boston. If MVI and other firms were to have rapid growth of standard products they would have to evaluate production and labor costs in a variety of potential sites. Moreover, the vision companies would not be surprised to see a substantial amount of work outsourced internationally by their suppliers if cost pressures become a more critical element in their standardized commodity products.

Pilot Products

In the current state of the industry, with so many new products, a substantial share of the production department's activity is centered on producing prototype and pilot products. (Prototypes number one to three and never leave the vision firm. Pilot products are shipped in small quantities, around ten, to the users.) Pilot products involve joint activity of the production and engineering staffs. The production department resembles a research laboratory and motivated the comment that such an environment may be the true "factory of the future." With new product lines just emerging and with demand patterns exhibiting substantial variability through time, products are rarely produced for inventory but are instead produced for specific orders. Some of the key components, such as image processing computers, are built without specific customer orders and are later integrated to a specific requested system.

Engineers and technicians work closely together to produce pilot products. System engineering is carried out mostly by hardware and software application engineers to meet end users' needs. The engineers put together such subsystems as optics, microelectronic chips, and the special and general purpose computers, along with special software written for the customer. Technicians assemble hardware products, using components purchased from vendors who make circuit boards, cables, cabinets, programmable controllers, wiring, etc. As the technology becomes standardized in the future, this is likely to change. However, the direction may be more a migration of the work of producing vision systems toward the technical people in the original equipment manufacturers (who make the robots or semiconductor chip assembly equipment, for example), in the system houses, and in the user companies such as the automakers, rather than to the blue collar workers either in the machine vision manufacturers or in the user companies.

Simplified User Operations in the Future

The industry perspectives include a sustained reduction in the cost of vision systems which may allow the full range of applications identified in the auto industry. Along with this cost reduction of vision systems there is a very strong belief that by as early as 1990 over two-thirds of installed vision systems will be operated by skilled workers rather than by engineers or programmers. Informed individuals believe that programming of the future systems will be accomplished by touch screens or other manual procedures rather than written instructions. As of 1985 over two-thirds of the vision systems were operated by engineers or programmers. This transition to the use of blue collar workers to operate vision systems should attenuate the adjustment difficulties as vision system adoption accelerates in light of lower prices.

Technology Management

The rapid growth of the machine vision industry will probably put some of the young scientists and engineers in supervisory positions in the near future. While these people are no doubt technically competent, they have usually not been trained for managerial skills and some may not have the aptitude for management. It has been suggested the current MBA (Master in Business Administration) programs in business schools may not be technology-specific enough for training managers in technology based industries either. It has been pointed out that the best marketing people in high technology industries have a technical background. Many leaders in both high tech and mature industries -- the semiconductor and the auto industries to be specific, both hard pressed by foreign competition -- call for attracting bright young people to manufacturing and educating them to design and manage flexible manufacturing systems. There seems to be a national need for some of the best business and engineering schools to develop and establish technology management programs to sustain the growth and reap the benefits of high technology industries. These programs are needed beyond what the firms themselves can do for management training on issues like communications, staffing, etc.

The information we have gathered so far indicated that even the nontechnical professional positions (for example, marketing) in the vision industry are filled with people who have had some technical education or training in other high tech industries. On the other hand, the support personnel, while young and skilled in such areas as word processing, do not get even elementary technical training to be "vision literate". There is a possibility that the "diminishing middle" phenomenon -- argued to be occurring in U.S. industry in general -- may apply to high tech industry even at its initial stage. That is, there is very little or no "middle" to begin with, as manifested by the clustering of employees near the two extremes of the technically trained spectrum. It should be noted, however, that the people at the lower end of this spectrum is by no means unskilled. They are only relatively less trained as compared to the professional and managerial people at the upper end. Moreover, these relatively less skilled people earn substantially higher than minimum wages, beginning at around $6 per hour or $13,000 per year, even though their earnings are an oder of magnitutde lower than those of their top professional and managerial colleagues.

Vocational Training

Different opinions have been expressed regarding the need for new educational programs for machine vision technicians to be established in formal educational institutions such as community colleges. Some believe that this is not necessary as well educated electronics technicians can be trained after they enter the vision industry. What is important is that they should be educated with the most modern electronics equipment, especially with very high frequency equipment (1,000 MHz) while they are in school. Others think there is a need for commuity college programs for machine vision in which technicians are trained to integrate video and electronics components. At present a good electronics technician without vision experience requires about 6 months of on-the-job training to become proficient.

From our discussion with the production department at MVI, one could infer that if the industry output growth occurs, it will generate a demand for highly trained workers in the major vision firms. Their demand for inputs may in turn give rise to employment of less skilled workers in the supplier chain; however, because of the pressure of international competition there will be incentives for keeping the labor input low, possibly through vision systems, as suggested by earlier discussion with Intel.

Cross Industry Movement

What we have not found in the employment characteristics are as interesting as what we have found. So far we have not found anyone in the vision industry who has been displaced due to automation or from declining industries. Even though the automobile companies are important customers for the vision industry, very few employees in the vision industry have previous work experience in the auto industry *per se*. (For example, only one technician at MVI has worked previously in the auto industry, as has been discussed previously.) Although General Morors has acquired minority interests in 5 vision firms, there is only limited evidence that it has tried to move any vision engineers from these firms to GM, though there have been some people who have transfered from GM, or from consulting firms serving GM, to some of these firms.

There seems to be a desire on the part of both small high tech firms and the large firms that acquire interests in them, to keep the company cultures and the employees with certain mind-sets undisturbed. There is also an unwillingness on the part of the established firms to build up divisions based on a technology which may change suddenly, and thereby make it necessary to phase out the activity to which they have committed. This raises further questions as to the effectiveness of retraining displaced workers from declining industries for job openings in high tech industries. As pointed out previously, fewer than 13 percent of the workers in the machine vision industry are blue collar workers, and larger firms may not want to take on blue collar workers when the technology is still highly uncertain.

Ripple Effect on Suppliers

Our interviews with the suppliers of the machine vision industry have been concentrated on the electronics firms. So far the employment effects have not been very much and have been mostly on the regional sales offices near the vision industry. For example, LSI Logic Corporation is an important supplier of microelectronic chips to MVI. Its total sales to the entire vision industry are less than $200,000, which is negligible compared to LSI Logic's annual sales volume of $140 million. However, the regional sales office of LSI Logic in Southeastern Michigan has certainly felt the impact of the vision industry in Michigan. A year ago, the regional sales office in Ann Arbor did not even exist. It was opened because of the vision activity. At the end of 1985, the office is a one-man operation, but expects to grow to 3 people by the end of 1986 (2 technical and 1 support persons). The number may grow to 8 to 10 in 5 years depending on the growth of the vision industry in Michigan. Other electronics firms we have interviewed gave us similar impressions.

IV. MACHINE VISION IN USER INDUSTRIES

This section will discuss the indirect employment effects of machine vision through its user industries. After an overview, the discussion will focus on the automotive and electronics industries, currently the two largest users of machine vision.

Overview

A recent survey conducted by the University of Michigan for the Automated Vision Association (Heytler and Smith, 1986) indicated that automotive and electronics industries are currently the two largest users of machine vision. Other major users include food processing, defense, aerospace, biomedical and pharmaceutical industries. Although the automotive industry is currently the biggest user, its share of the market is expected to decline from 49 percent to 31 percent by 1990, when the electronics industry is expected to take a top share of 36 percent.

Although the indirect employment effects of machine vision through its suppliers have been minimal due to the current size of the industry and the nonlabor-intensiveness of its supplier industries, the application of machine vision could have extensive employment impacts on the users of machine vision: some job categories gaining substantially while others contract and with secondary effects on suppliers in these same directions. The primary source of employment contraction is in the substitution of vision systems in production.

Automotive Industry

The auto industry is currently the largest user of machine vision, and the potential for future application is enormous even if auto does not remain as the number one user. For example, General Motors has identified 44,000 potential machine vision applications, including more than 12,000 uses in assembly operations alone (McDonald, 1984). For both technical and economic reasons, how many of these potential applications will become actual installations is highly uncertain. At present there is a great variety of machine vision inspections of parts. In final assembly, there are significant vision applications in place for dimensioning, paint inspection, robotic windshield installation, and inspection in systems used to seal joints in the welded auto body. All of these examples involve actual or potential feedback control functions. Very preliminary evidence on the "typical" extent of direct labor substitution per vision application in the auto industry suggests a net reduction of from 2 to 6 workers. If the average of labor displacement were 3 workers per application, then a potential reduction of about 132,000 production workers could occur in GM. This estimate is consistent with study findings from both the United Auto Workers (UAW) and the Industrial Technology Institute.

Further, people we talked to expect the use of vision systems to expand at a rapid rate at Ford and Chrysler as well. To illustrate, Ford plans to use vision systems for paint inspection in the very near future. Even more important is the ripple effect on tool and die making, which is very labor intensive. That is, with flexible manufacturing aided by machine vision, there will be a substantial reduction of the large number of new tools and dies which are normally needed for traditional dedicated manufacturing, and not just in the auto industry. Therefore, the potential worker displacement in the tool and die industry can be very substantial. Whether an adjustment to such employment effects would be difficult to absorb depends on several factors, including favorable effects on the demand for output (and hence workers), which could arise from a cost reduction for the product, the rate at which this new technology is introduced, and the retraining and reassignment possibilities for those currently employed, as stipulated in the UAW-GM contract.

Others have argued that a more realistic labor saving per application is in the range of 1/2 to 3 workers. If we say the average in this calculation were 1 1/2 workers per application then the 44,000 applications would displace perhaps 60-65,000 workers, at the micro level, or about half of the 132,000 mentioned above.

A reason for the lack of consensus on the extent and speed of labor displacement is the uncertainty about the rate at which vision systems can be standardized and have their costs lowered to the point that as many as 44,000 applications are realized. Even apart from costs, there are practical difficulties of the sort illustrated previously in the use of vision systems for paint inspection. Realizing that the 120,000 is probably on the high side of these labor displacement conjectures for 1990, what are some of the factors that would attenuate this full labor-substitution?

First, it has been estimated that a 10 percent reduction in the price of automobile implies a 10-15 percent increase in their sales (Houthakker and Taylor, 1964). If robotic vision systems increase productivity and lower the auto industry's labor cost by say 20 percent, by how much would they lower the overall cost of an auto? Installing and operating the vision system has a cost. Suppose this equals half of the labor savings. If so the overall cost reduction would be 10 percent. The share of total production costs represented by the auto firms is approximately 40 percent. This implies that a 10 percent reduction in their costs, if translated into price reductions via competition, would lead to a 4 percent decline of the market price. If the price elasticity of demand were as large as 1.5, then sales would increase by 6 percent. Overall then the 20 percent reduction in labor requirements per vehicle would be partially offset by a 6 percent increase in the number of units sold.

From another perspective, the labor reduction offset could be greater since machine vision may increase international cost competitiveness of the domestic industry and prevent rapid erosion of the domestic market to imports. However, the calculations above suggest that the employment offset via output effects would be important but not enough to preclude ne contraction of industry employment.

New employment in the vision industry and its suppliers can be calculated. It appears thac about 1 vision system has been produced per employee per year, and in the future the number may go up to 2-3 systems per employee. If the auto industry were to use 90,000 vision systems (assuming that GM represents somewhat less than one-half the applications) which lasted on average 5 years, then the annual employment in this supplier industry needed to sustain such a stock of machines would be on the order of 11,000 employees. Their chain of suppliers (including consultants and trainers for the development and diffusion of the vision technology) might imply another 11,000 because of robotic vision systems. There would be an offset in the vision industry and its suppliers of about 22,000 with an additional offset in the machine tool or robotics industry.

If we were to guess that these hardware elements and their suppliers were to imply an employment increase of about the same amount as the vision systems, one could come up with an approximate increase in employment of about 45,000 outside the auto industry to offset the employment reduction of 270,000 (a little over twice 132,000) inside the industry. In this context output effects and employment shifts into the vision and robotics industries start to look like significant offsets to the direct employment declines in the industry, and, as noted above, the whole process may prevent dramatic loss of market share in the auto industry which would have far greater employment and adjustment cost consequences.

Our investigation indicates that the workers displaced with the introduction of vision systems are retrainable and reassignable. For workers to be retrained and reassigned, the user companies must have some form of attrition policy of the sort embodied in the current GM-UAW agreement (the job bank). The transition process can occur more easily during good times since the voluntary separation rate is higher, allowing for reductions in employment without layoffs. For workers who remain on the job or fill new jobs created by machine vision, companies like General Motors have both internal and external (through vendors and formal educational institutions) training programs in machine vision for skilled tradesmen, production workers, and staff engineers. Such training is emphasized to accelerate and smooth the introduction of machine vision technology into the user companies.

Electronics Industry

Vision systems are being applied at an increasing rate to manufacturing in the electronics industry. As in the case of the auto industry, the application of machine vision is mainly for inspection and assembly, for the purpose of increasing quality and productivity as well as meeting clean room requirements.

The use of optical inspection in the process of making semiconductor chips has been standardized to the point that four stages of optical inspection are generally applied. The first optical inspection, or the "first opt" in the jargon of the industry, is for incoming quality control (IQC) of the wafer materials. The "second opt" is to detect mechanical defects at the die-attaching process; the "third opt" is for the wire bonding process; and the "fourth opt" is to check the finished encapsulation. Machine vision has become essential for some of these inspections which have become so demanding (for example, using nearly 90 criteria to check quality at one stage) that manual inspection has become almost impossible. Furthermore, the demand for quality control in chip production has increased dramatically -- the number of defects having been reduced by several orders of magnitude.

The main motivation for using vision in semiconductor chip assembly is no longer labor saving since the direct labor cost has dropped so much in recent years due to automation that it has become relatively insignificant. (For example, direct labor for certain chip production at National Semiconductor is only 1 percent of total cost.) In addition to quality improvement, as discussed before, the major reasons for using optical inspection are material savings (material cost being a major fraction of the total cost), and increasing throughput. The latter, throughput, is important in view of the large capital cost (typically $20 million for 10-million-unit capacity) and the need to reduce production cycle time for speedy market response (from the order of 5 weeks down to much less than one).

In the semiconductor industry, labor displacement by automation, and by machine vision in particular, has been dramatic in selected areas. For example, LSI Logic used to have a human inspector at each of the die-attaching and wire-bonding machines in one of their production lines. Now a single operator can handle 10 such machines, and each of these machines has increased throughput more than 3 times after the manual inspection was replaced by optical inspection. Thus, labor productivity in this process has increased almost 30 times. Other semiconductor manufacturing processes are also using fewer production workers. Of the 1,400 employees in LSI Logic today, half are in production. It is probable that nearly all these workers will be reassigned to nonproduction work in 15 years. Again, it should be emphasized that the major contribution of flexible manufacturing systems using vision to profitability in electronics manufacturing is no longer via labor savings.

Another application which highlights the role of vision systems is in the inspection of electronic devices surface mounted to an electronic circuit board. Orders for these products are often custom orders for relatively low volumes, implying a need for cost-effective, flexible manufacturing. One method of achieving flexible manufacturing is to have boards populated to specifications (putting the right components in the right locations) by passing them through a series of high-speed, automated workstations. At each workstation the product is taken from inventory trays, worked on and returned to inventory trays. The trays are then transported to the next workstation. Through a sequence of production steps or modules the final product is built up and completed. This "islands of automation" method requires a fair amount of labor to staff each workstation, transport the product and to verify the final products' match with the design requested by the customer. As noted below, just visually inspecting the completed board may represent 40 percent of the total cost.

The state-of-the-art approach to this production process uses a computer design of a board to achieve certain functions desired by the customer. These computerized instructions are then transferred to an automated assembly line which adds components at various workstations. The product is transferred by conveyors rather than people. In-process buffers (holding areas) are used to permit flexibility in the flow at various production stages and to ensure that possible key points involving expensive machines are not held up by temporary malfunctions further down the assembly line -- the buffers are designed to make fullest use of the most valuable equipment. Reels of plastic tape containing electronic components are fed into the automated assembly equipment and placed on proper locations on the board according to the computer designed specifications.

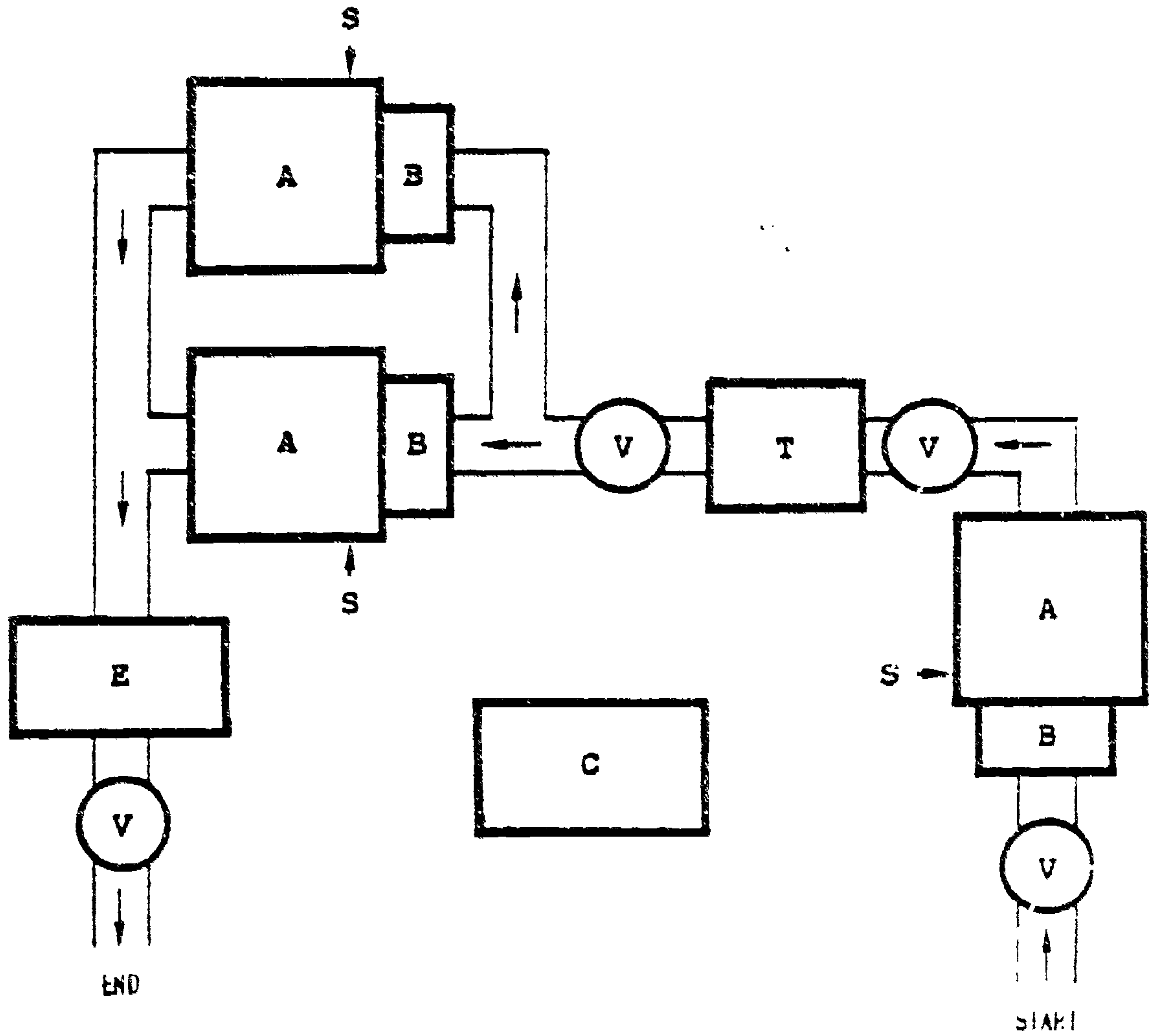
In this type of production arrangement, vision systems are used not just at the end of the line for final inspection but are also used at key intermediate points at which substantial, irreversible (or costly) value is added (SIVA) to the product. In the production process for boards, additional soldering or adhesion of components may make them irretrievable. These SIVA points are <u>preceded</u> by vision checks to ensure that a faulty intermediate product is not given additional input. Moreover, the vision system can send signals about the faulty product to a central control computer which can diagnose the problem and identify the prior location of the problem. Through a centralized computer check of the inprocess activity as recorded by vision or other measurement/verification devices, it is easier to debug the production of small lots. That is, vision and computer assessment can reduce the fixed costs of verifying the manufacturing compliance with the design, and in this way vision is critical for the use of flexible manufacturing systems.

In a system of the type just described, vision reduces final inspection costs, reduces the cost due to putting good resources after bad (the SIVA points) and permits a rapid verification of the manufacturing activity and its being true to intended design. The whole system of flexible automation can greatly reduce production costs. With current vision system costs and custom design of the automated assembly line, it appears that the system costs can be recouped in 2 to 3 years even where wage rates are somewhat below the U.S. manufacturing average. Moreover, quality and delivery time reliability are improved. A stylized layout of such a manufacturing system is presented in Figure 2.

In this stylized layout some material such as an unpopulated board (S) is placed on the assembly line where it then moves to be inspected for flaws by a vision system (V). It then moves to a buffer (B) of inprocess inventory to ensure full use of the assembly equipment (A) which places additional components (S) on the board according to a design specification. The product then travels to a vision station (V) where it is inspected before soldering or some other treatment affixed components to the board in a more permanent fashion. The sequence of vision-buffer-assembly is repeated in the next segment of Figure 2, but now there are two assembly stations which run in parallel.

What are the functions of a parallel assembly layout of this type? One advantage is that if there is a timing need on the part of customers for at least a share of their order and there are possible malfunctions in the assembly equipment, then a share of the order can be completed even if one assembly station is idled. This is similar to a firm having potentially redundant labor to produce a product in the event of absenteeism which could limit output. Another rationale is that in the absence of malfunction, the presence of two assembly stations at this location simply allows more production capacity. A third possible function would be to produce two variants of product simultaneously, routing one through the upper loop and the other through the lower loop rather than running separate batches at different points in time.

The main implication of the schematic in Figure 2 is that vision systems <u>combined</u> with other elements in flexible manufacturing -- computer aided design, programmable assembly stations, computer control and monitoring of the overall system -- give rise to a manufacturing system that can produce a variety of different products and which operates with a very small labor component. Although such flexible manufacturing systems (FMS) are justified not so much by reduction in numbers of workers as by improvements in yield, quality, capacity and throughput, the labor displacement associated with such systems is essential for achieving cost competitiveness in U.S. manufacturing. This continued pressure from international competition should accelerate the introduction of such technology. As discussed in the next section, it could lead to the movement of some offshore production back to the United States, and to this extent lead to greater manufacturing employment in the United States or other high wage countries.



A: Assembly point
B: Buffer of inprocess inventory
C: Central computer
S: Supply point of material to the production process
V: Vision inspection point
T: Treatment (e.g., heating, soldering to affix components)
E: Electronic Test

FIGURE 2

VISION SYSTEMS IN FLEXIBLE MANUFACTURING OF ELECTRONICS

V. INTERNATIONAL COMPETITION IN VISION AND MICROELECTRONICS

In this section we will discuss international comptition in both machine vision and microelectronics (semiconductor chips). There are two reasons for a joint discussion. First, as mentioned previously, the electronics industry is both a major supplier and a major user of machine vision, and therefore the two industries are intertwined. Second, vision and microelectronics are both high technology industries, and microelectronics may prove to be a precursor of machine vision as far as international competition is concerned.

Current U.S. Dominance

At present, the United States enjoys a clearly dominant position in the machine vision field, technically and commercially. Although many components in the vision system, especially optical components like cameras and lenses and some of the electronic chips, are imported, the total system engineering and sophisticated software that are critical to the functioning of the whole system are by far mostly provided by the U.S. firms. The leadership position in software, and perhaps in such components as the microcomputer, is likely to be maintained by the U.S. in the foreseeable future. System engineering for the more standardized products, however, may encounter increasing foreign competition.

LSI Logic, an important supplier to the vision industry, estimates that 15 percent of the silicon chips purchased (25 percent in value) by vision firms are proprietary products, products which are customized by a single producer on a proprietary basis; and the remaining 85 percent are commodity products, products which are standardized and can be made by a number of producers. It is the latter, the commodity chips, which are vulnerable to import erosion. Being a 100-percent proprietary product producer, LSI Logic is not very much concerned about foreign competition at this point.

Status of Foreign Vision Industry

We have devoted some effort to determining the nature of the vision industry in Japan and have had discussions with Mr. Kaoru Naito, an official with the Science and Technology Agency on loan to the National Institute for Research Advancement (NIRA) in Japan. A current interest of NIRA is the impact of the "microelectronics revolution" (NIRA, 1985) but to date we have not been able to identify a specific study of the vision industry in Japan. Industry observers in the U.S. claim that investments -- at least for export purposes -- have not yet taken place in Japan because the nature of the markets and technology are not yet well defined. We will discuss this point further.

Standardization of systems as well as diffusion in applications to other industries are predicted by those in the industry. Applications will grow in such areas as inspection of surface mounted devices (SMD) in the electronics industry and inspection of foods in the harvesting of crops. While the growth of applications should sustain employment in the vision industry, standardization is seen as leading to increased international competition in the supply of vision systems. Presently there is little direct foreign competition in the form of stand alone vision systems. However, there are vision subsystems built into some assembly equipment from abroad. An example is the equipment made by Shinkawa of Japan which attaches wire bonds to silicon chips. Another example is the imported robots with built-in vision and other kinds of sensors. In this area, the long-term implication of U.S.-foreign joint ventures such as GMF, a jointly owned subsidiary between General Motors and Fanuc, can be very significant, even though the vision portion of GMF's $200 million per year sales is only 3 to 5 percent at present and their vision systems are mainly U.S. technology.

Observers in industry believe that the Japanese firms will enter the international market of machine vision directly when a large fraction of the vision systems become standardized, when the industry as a whole becomes profitable, and when the total market is about $1 billion. The present trend would suggest such an entry in about five years. The standardized vision systems will then have to compete more on cost than on differentiation of product (Porter, 1985), resulting in U.S. firms moving production of such vision systems overseas and having a hard time competing with the Japanese, at least at the low-cost standardized end of the product spectrum -- deja vu of the microelectronics competition. In any event, there are foreign machine vision firms that can enter the international market aggressively when the time comes, and the continuing dominance of U.S. firms in the vision field is by no means assured.

At present, although the vision systems made in the U.S. rely on components from abroad, the system design, assembly and programming are done domestically. The previous discussion on proprietary and commodity chips speaks to this point. One survey (Heytler and Smith, 1986) shows that only 25 percent of vision systems in use by 1990 will be standardized because of the complexity of vision applications. However, many believe that within 10 years over half of the systems will be imported, although there are differences of opinion here. This is part of the overall move toward a smaller number of standardized products which can fill a variety of applications, thus increasing the profit margin. The industry has a narrow line to stay on. On one side of the line, lack of standardization escalates unit costs and discourages a wide range of applications. On the other side of the line, standardization of product and simplification of software application increase the scope of international competition.

Impact of Vision on Offshore Production

Industry people were asked to assess the impact of vision systems with respect to bringing "onshore" activities which have previously been produced "offshore", especially in Southeast Asia. In auto industry applications, the feeling is that vision systems would help to slow or possibly halt the trend toward offshore production of vehicles and components. The potential of advanced automation to reverse the trend of locating labor-intensive semiconductor production activities in developing countries has been suggested for several years (Rada, 1981; Ernst, 1982).

A prime example for onshore electronics was the inspection of surface mounted devices on boards to be used in computers and related applications. Several people noted that as much as 40 percent of the cost of producing some of the boards is accounted for by inspection. A reasonably complex board might take an entire 8-hour day to inspect, requires the worker to wear special garments to protect against dust, and is a job which is very demanding. Currently, vision systems for inspection can accomplish the task in about 15 minutes. Such a dramatic reducti in labor input can bring onshore a large share of these activit s.

An example of the onshore movement is LSI Logic, which used to have 100 percent of their plastic encapsulation for microelectronic chips done overseas. Partly due to vision applications that cut costs of bonding and inspection, 85 percent of this activity has moved back to the U.S. in the last two years. However, as noted previously, practically all LSI Logic chips are proprietary products, for which there is a distinct advantage to get design and process engineering together, and to locate wafer production, chip fabrication and packaging in close proximity to one another in order to reduce time in responding to customers' demand.

One question arises: why not use the vision system in the current offshore location? Even if the labor component has been reduced there should be some cost-saving arising from lower wage rates. The answer is that, for proprietary products, onshore production reduces inventory costs and delivery and product development times, and these advantages are sufficient to rationalize domestic production as long as direct labor costs are kept within reasonable limits by vision. For commodity products, however, offshore production remains attractive and automation including vision is indeed being planned for offshore production. For example, Advanced Micro Devices (AMD) is considering building a highly automated microelectronics plant in Thailand that requires 500 to 600 employees, instead of 3,000 employees for a nonautomated plant with the same capacity.

In sum, although machine vision can contribute significantly to bringing some of the offshore <u>proprietary</u> (<u>customized</u>) chips manufacturing back to the United States, it is not the key determining factor in making the on/off-shore siting decision, and certainly not yet bringing <u>standard</u> (<u>commodity</u>) chips manufacturing back onshore. From the standpoint of labor cost, which is the main motivation for offshore production originally, inspection alone may account for only 15 percent of the direct labor payroll for many electronics production. In the production line that is not highly automated for many chips, direct labor is still used substantially for machine operation, data recording, shipping, storing, and other material handling functions as well as inspection. Therefore, machine vision alone would not reduce direct labor costs substantially for such production.

On/Off-Shore Siting Decisions

We have interviewed several facility planners who consider on/off-shore siting decisions for electronics manufacturing. First, a number of traditional factors enter into their deliberation. In their consideration of labor cost, indirect labor (process engineering, shipping/receiving, maintenance, administrative staff, etc.) is as important as direct labor. The skill level of the indirect labor pool, and therefore access to good educational institutions, is an important factor in siting. The quality and discipline of direct labor -- not just their skill and trainability, but also their work attitude and work ethic -- is also important (and favors Southeast Asia). The investment incentives provided by foreign governments, such as free trade zones, opportunity to get low cost financing, depreciation allowance, tax holidays, and training subsidies are the next important category of factors to consider. Geographic proximity to market has been an important factor, and the rapidly growing areas like Southeast Asia are important markets for commodity chips.

In addition to the above factors which have been traditionally considered, a number of originally unexpected advantages of offshore production have become important. For example, the proximity to quality and low-cost suppliers (equipment vendors as well as parts suppliers for quartz, ceramics, wires, frames, glass, etc.) is now often more important for standard chips production than proximity to market. Offshore plants now include quite advanced automated production facilities. Most importantly, when the U.S. microelectronics firms moved their assembly operations to the Pacific Rim in the late 1960s and early 1970s, the manufacturing infrastructure, including the parts suppliers and manufacturing engineering, moved to that area also. Japan is now an important source of high quality semiconductor materials and manufacturing equipment, and Southeast Asia has some of the most capable, experienced, and relatively low cost ($12,000 per person-year) manufacturing engineers. Some simple R&D work has been done by good quality hardware and software engineers also at a fraction of U.S. salaries. In addition, for some countries like Japan, the plant location may be important from the standpoint of market penetration and tariffs.

All the above-mentioned factors have led to a decline in U.S. manufacturing, making many U.S. manufacturers "hollow corporations" (Business Week, 1986). There are possibly inexorable forces toward more uniformity in world wages through the process of international trade. The far higher U.S. wage and standard of living (or the expectation) is supportable only when there were vast differences in knowledge and productivity of workers across countries. Advanced automation will be, at best, a force to slow the trend and allow more time for our own population to accept a more modest share of global wealth.

Strategies for International Competition

Among the semiconductor manufacturers there appears to be considerable diversity in strategies for meeting international competition. One strategy is to compete in central product lines, using advanced manufacturing techniques and domestic production. This strategy is based on the premise that in order to keep production technology competitive the U.S. companies must stay in the business of making the standard products such as memory chips (Uttal, 1986). Another strategy is to compete by identifying new products in central product lines but to organize most of the production activity offshore. Yet another strategy is to focus on smaller market niches, primarily in the U.S. market and to try for more modest improvements in manufacturing productivity.

The strategy of directly meeting international competition in central product lines through advanced manufacturing techniques is being employed by National Semiconductor. They are building a new manufacturing plant in California using the concepts developed under an eight-year project (started in 1980) called Project Odyssey. This project, aimed at the capability of making high-quality, high-volume and cost-competitive chips that can be located near the market anywhere in the world, is similar to General Motors' Factory of the Future program: it is based on computer-integrated manufacturing and will make extensive use of vision systems for inspection. They have also been concerned with standardization for their information systems and have developed standardized languages and computer networking protocol parallel to the MAP proposed by General Motors. It is expected that using advanced manufacturing systems this plant, when opened two years from now, will employ 200 people rather than 4,200 people. The added hardware cost in the plant will be about $20,000,000. The plant so outfitted may cost about $80,000,000 rather than $60,000,000. The apparent return on the added investment is enormous. If one worker costs $25,000 per year then reducing employment by 4,000 will achieve a saving, in just 1/5 of a year, large enough to pay for the added capital cost.

As a leader in manufacturing technology, National Semiconductor has had some of its managers bid away by other electronics firms which are intent on upgrading their manufacturing technology. Does this mean that this technology will quickly sweep the U.S. electronics industry? There are some factors which would argue against this. First, National Semiconductor is the industry leader and the other firms have not invested as much in this area. Second, the project has required a major effort to implement. To illustrate, the planning phase has taken 5 years to date and the implementation phase now requires a major effort including the involvement of 60 technical people at National Semiconductor plus 25 to 30 people from Digital Equipment Corporation (of Massachusetts) who are in residence during a period of a year or so. Third, much of the human resources for manufacturing engineering now resides on the other side of the Pacific Basin. Companies such as Advanced Micro Devices have many of their best manufacturing engineering people in places like Thailand. These countries have responded to U.S. offshore production in their countries by training very capable people in these areas of engineering who work for $1,000 per month rather than $5,000 per month!

The rather widespread strategy of capturing smaller, high value-added markets seems to be attracting most of the semiconductor industry's attention at this point. This strategy focuses most of the company's energies on product innovation rather than process innovation. Moreover, achieving great flexibility and system integration is required before advanced manufacturing systems can prove cost effective relative to offshore production or currently used techniques. These techniques can be primarily described as "islands of automation" connected by labor effort and in which a lot of the quality testing is done by people.

The Learning Curve Concept

The fact that there does seem to be a lot of activity and reorganization in the electronics industry means that there should be an interesting comparison of the similarities and differences in the application of vision systems and related computer technologies in the electronics industry and in traditional manufacturing. A more general question which comes out of this is one of changes in the frontier which describes production costs (and production technology) and product diversity. There is a substantial literature on the learning curve (Hayes and Wheelwright, 1984) which postulates a shift from small volume, batch-processed goods as a new market is developed, to high-volume, automated production as the market broadens and matures and as the product configurations with the greatest demand are identified. Firms which are successful can move more quickly down this product/process continuum and use their marketing/processing experience to gain a dominant marketing and production position.

With international competition there is a need to move down this curve more quickly and to identify new markets in which to pursue this goal. Because of high U.S. labor costs and improved marketing efforts by foreign rivals, U.S. firms may be losing out in terms of profitability and employment in the intermediate stages where there are mid-range volumes which can be produced cost effectively only if flexible manufacturing systems can be employed. In short, vision-assisted manufacturing systems could be thought of as representing a change in this volume/production technology frontier.

This can be set out in Figure 3. Horizontally, there is increasing product diversity in a given production site. For a very new product series, there may be a substantial variety since the market may be small and the most marketable product characteristics may not have yet been identified. In this circumstance production is likely to be carried out on an order only basis and produced by job shop technology in very small "runs". This is the circumstance in many of the vision firms where products are produced on order rather than for inventory (undesignated customers).

As the company learns about demand for different product characteristics it will operate at higher production volumes and more along the B-curve in Figure 3 to produce higher volumes using some standardized production activities with some capacity to produce product variety. For example, core components may be built for inventory and conditional on customer orders. Products with specific features beyond the core will be produced to order. Finally, there is a stage where large scale markets have been identified and a firm will produce using dedicated automation and inventory variation. In the literature there is also a discussion of moving down this frontier quickly so as to achieve a cost advantage over rivals.

Another dimension to be considered is technological change. The cumulative improvement in process technology generally available results in the shift of the "learning frontier" from A to B to C (see Figure 3). If we think of early manufacturing technology it allowed for movement along a frontier such as A. In this stylized version of process technology of 1900, the actions of an individual firm in exploring markets and learning about production techniques would generate more limited potential to progress to more cost-effective production technology. It is our belief that vision systems as part of the factory of the future offer the potential for a frontier more like C, which is significant for medium volume, medium diversity production. This frontier is not shifted out very much from B at either endpoint: very low volume or prototype production will still involve jobshop technology, and large stable mass markets will continue to require dedicated automation.

What the new, flexible manufacturing technology should achieve is an outward shift in the middle range. Medium volume production should be amenable to flexible automation systems rather than islands of automation, for example. This change has implications for U.S. manufacturing. First, if the U.S. is a technological leader in this area it will be able to operate with lower production costs in this middle range. Second, if the technology becomes universally available, it will mean a more capital intensive production technology (movements along K) which should help to offset U.S. production cost disadvantages and lead to production near final markets. Trade may take place more in

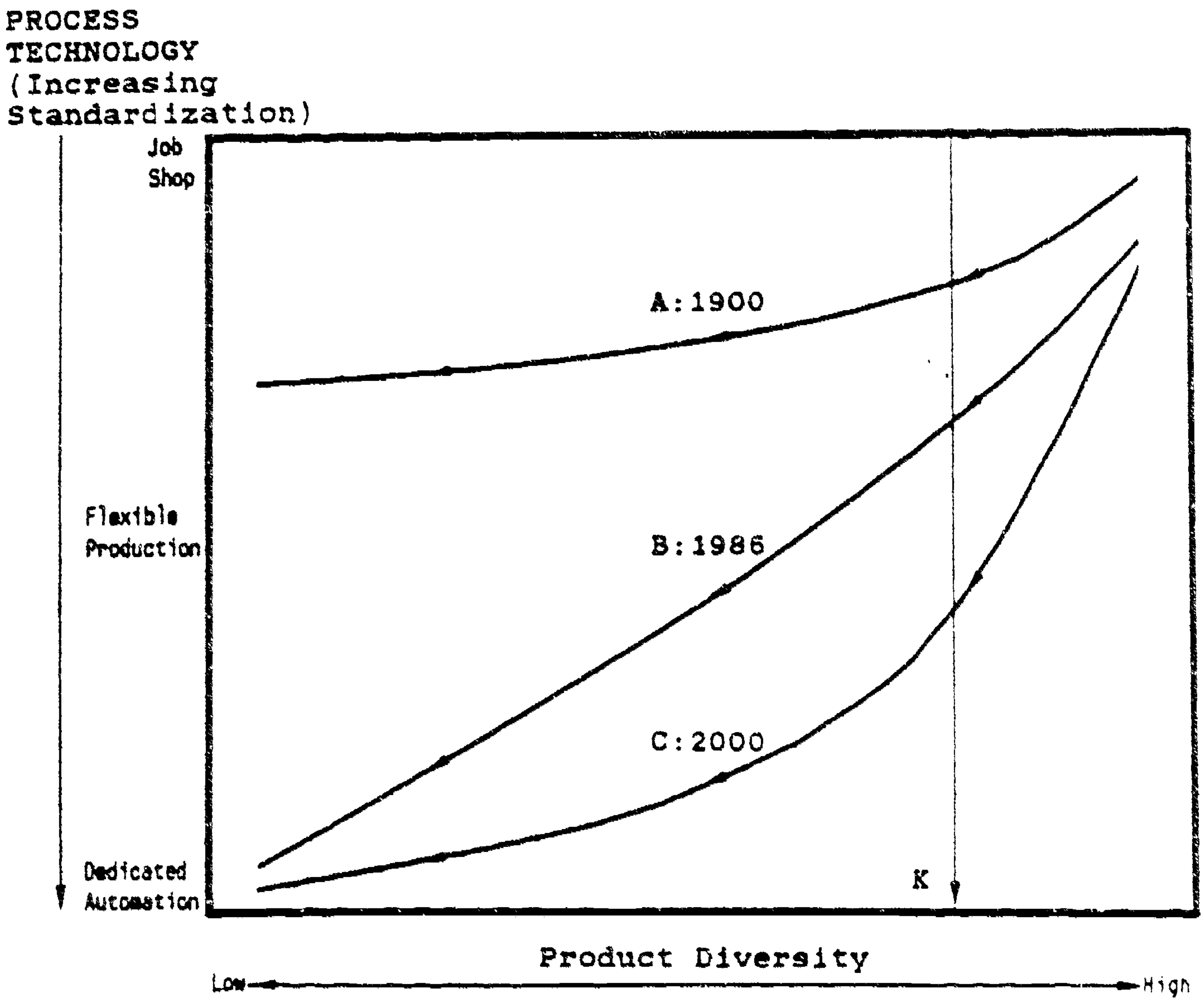


FIGURE 3

PRODUCT AND PROCESS LEARNING FRONTIERS

intermediate capital goods and system design. Third, the vision industry itself can also be a beneficiary of its own technology: for the vision industry product technology improvements also represent potential process technology improvements if they are used to lower the costs of the industry's own products. From our discussions with suppliers and users of the vision industry products, there was a concern that smaller firms would not employ vision systems until they became more standardized and until the costs were reduced significantly.

In this project, we have not been able to inventory the complete range of other applications which might be affected by vision systems. As a consequence we do not have a feel for the range of industries in which international production locations would be affected. However, preliminary evidence such as has been described suggests substantial opportunities for job saving and job retrieving from lowered costs associated with vision systems, but probably with many of the caveats which apply to the semiconductor industry. Further, in many of the vision applications there appears to be a large quality improvement. Vision systems for inspection of paint flaws are capable of catching many more problems than manual inspection can. In addition, if the record of flaw patterns is computerized and analyzed, the downstage problems can be signaled back to an earlier stage in the process for timely correction. Although some of this factory network feedback has been implemented to date, indications are that vision will continue to help increase quality as well as productivity through such feedback, and thus international competitiveness of the industries that use it. Vision systems are regarded as essential for more extensive application of industrial robotics. They are believed to be essential for the independent performance of many tasks and are a part of the computer networks essential to achieving flexible automation.

Prospect for Export and Two-Way Exchanges

The machine vision industry has also engaged early on in exports. For example, MVI's first project was a sale to Seiko, using vision to help set the right time on Seiko's digital watches to be shipped to different parts of the world. International sales offices and joint ventures are set up by many vision companies to expand their foreign markets. Joint ventures are likely to involve foreign employees to provide marketing and application engineering functions, with an indirect positive employment effect on the U.S. workers, and to involve import of standard components and vision systems to the U.S. market, with offsetting effects on the employment of U.S. workers.

It has been stated that "cooperation and competition may be viewed as complementary rather than mutually exclusive objectives; and strategies for success in the global market as ultimately benefitting international trade and the world's quality of life" (National Science Foundation, 1986). In the areas of microelectronics and machine vision, joint ventures have been set up for mutual marketing and technological benefits between U.S. and foreign firms. Two important joint ventures between U.S. and Japan in these areas are GMF, a jointly owned subsidiary between General Motors and Fanuc in the robotics area including machine vision for the robots, and a cooperative technology development between KLA Instruments and Shinkawa in applying vision to semiconductor manufacturing. Another interesting joint venture, in the area of microelectronics with nothing to do with vision, is between LSI Logic and Kawasaki steel company, which provides low-cost capital and access to certain technologies in Japan, including process technology for dynamic random access memory (DRAM) and for furnace technology common to steel and semiconductor materials.

In thinking about the role of international competition, we can possibly separate the U.S. vision industry *per se* from the user industries. It is possible that the U.S. vision industry itself could be displaced by international competition in the next 10 years. At the same time, the application of imported vision systems would allow traditional domestic manufacturing industries to lower their production costs and strengthen their international competitiveness. To illustrate, a substantial element in the Saturn (GM), Alpha (Ford), and Liberty (Chrysler) projects involves applications of vision systems in the final assembly process. A major goal of these projects is to restore the cost competitiveness of domestic auto manufacturing, which can be achieved with the help of vision systems made by any country.

Another model of international competition for the vision industry *per se* is one in which the U.S. vision firms will continuously explore and develop frontier products. The standardized products, with large and well-defined markets are subject to extensive competition from abroad. In this environment the vitality of the domestic industry will depend on a continual flow of new research ideas, and the role of university and research laboratory links to the industry will become of even greater importance than they are today. Perhaps differences of this sort explain why those in the industry's leading technology firms are more optimistic than the average vision firms about retaining these activities in the United States.

A pattern of the sort described above has characterized the West Coast electronics industry. From the 1960's to the late 1970's, the share of the California labor force in the electronics industry fell from 4.1 percent to 3.6 percent (Stafford, 1982). This moderate decline in employment share obscures rapid change in the detailed subindustry categories. Specifically, there were dramatic shifts out of (by now) traditional electronics sectors such as television manufacturing and into the leading technology industries of the time. The industry has been characterized by successive moves into these leading technologies, and this has been slowed until just recently by the rapid appreciation of the dollar and increased international competition at the leading edge. An environment of this type could occur in the vision industry as new directions in automation evolve from previous simple robots, to vision systems, to tactile capacities and eventually to artificial intelligence applications in manufacturing.

VI. CONCLUSIONS AND IMPLICATIONS FOR POLICY

In this concluding section, we will first try to provide succinct answers to the research questions posed in the introductory section of this report. Then, instead of repeating the major findings that can be found in the executive summary, we will extrapolate from this case study of machine vision to discuss a number of policy implications that relate to the employment effects of high technology in general.

Answers to Research Questions

The rate of job creation in high technology is roughly proportional to the rate of increase in sales volume. In the case of machine vision, this has been about 100 percent each year for the past few years. However, the rate of growth is expected to slow down to about 50 percent per year for the next five years.

Most of the new employees for the vision firms have come either directly from schools or from other high technology firms, including other vision firms. As a result, their average age is relatively young (about 30) and their industrial experience relatively limited.

Most of the employees in the vision firms are generally happier in their current jobs. They feel confident about their future career growth with the whole machine vision industry even when their own companies may be under financial difficulties.

Most of the jobs in the new vision industry are highly technical in nature, and even the marketing people frequently are expected to have a technical background. The support people are usually screened for their enthusiastic work attitude as well as for their skills for using modern equipment.

The technical professionals in the vision firms spend a substantial portion of time to get further training -- almost on a continuing basis as the technology is still under rapid change. The technicians in these firms usually need 6-month on-the-job training to become proficient in their work. Practically all vision firms provide the training programs, which are also used for their customers.

The United States enjoys a dominant position in the machine vision field at present. However, foreign firms exist in the field and are anticipated to enter the international market when a large fraction of the vision systems become standardized, when the industry as a whole becomes profitable, and when the total market is about $1 billion.

If the present patterns in high technology globalization continue in the future, foreign vision firms will gain a significant market share in standardized vision systems, and the U.S. firms, after a shakedown in the industry, will maintain strong positions in the sophisticated customized vision systems.

Role of Science & Engineering Education

There is no question that strong science and engineering educational programs are needed to train technical professionals for high tech industries, including machine vision. However, to help the young professionals and their companies to survive in these industries, and to help the U.S. maintain its international competitiveness in the high tech business, it is increasingly important for these technically trained professionals to learn the basic concepts of technology management, and to be exposed to experienced managers while the young professionals are still in school.

Rapid technological change and globalization are two important trends in the growing industries, and new courses and new curricula in technology management are needed in the context of these trends. Such new curricula would require innovative cooperation between engineering and business schools, with the participation from other relevant disciplines. What our study has shown is that there is increasing international competition at higher skill levels -- U.S. engineers are now being compared with those in other countries and the latter often have a wage which is one fifth ofthe U.S. wage.

Within engineering, practical system engineering should be emphasized since many new technologies, such as machine vision, cannot serve the customers' real interests unless they become properly integrated with other relevant technologies in a total system. As the promising future for U.S. manufacturing lies in the direction of producing customized, high value-added products (see Section V), the teaching of integrated manufacturing that links manufacturing with design engineering, and even with worldwide procurement and marketing, cannot be overemphasized.

Role of R&D

Whole new industries, such as machine vision, have been spawned from basic research and long range development programs. One of the most important strengths of the United States is its basic research capabilities. The government's role in supporting basic research has been quite clear. However, long range development in the civilian sector has been supported mainly by a limited number of large technology based companies. Medium and small high technology companies, such as MVI in the focus of our case study, have very thin financial backing for their long range development efforts. Public and private policies are needed to encourage innovative financing arrangements to support long range development involving medium and small high tech firms.

The linkage between basic research long range and short range development work is also important. The United States has been strong in running against its rivals in individual dashes but not in relays. Teamwork among universities, large and small technology based firms will be needed to help the U.S. do better in future relays. An example may be for a university to do basic research, with the result developed for practical application by a small firm, and integrated into a total system by a large firm. Another example is for a number of firms to work out standards and protocols for system integration, as is being done on MAP. An effective way to develop team work, and to faclitate technology transfer, among organizations is to have people move or circulate among them. While this is frequently done within a single company (from research to engineering to operations), tradition and institutional policies have not encouraged this to happen among organizations.

Employment Growth and Substitution

Within the machine vision industry, total employment is expected to grow rapidly although individual firms may merge or go out of business in the anticipated shakeout -- a phenomenon quite typical of emerging high technology industries. Even though the workforce in these industries is relatively young and thus their relocation cost relatively low, there are still transitional costs that may deter desirable and efficient moves. For example, in spite of changes in recent years, there are still difficulties for workers changing companies to have certain types of insurance coverage (e.g., major medical) and pension benefits continued without interruption. These difficulties may be alleviated by new policies.

The potential labor substitution of machine vision in the user industries has been estimated to be quite substantial even though the actual labor displacement is uncertain. This case study has made it clear that the displaced workers in the user industries are not likely to land the new jobs created by the new technology. One policy implication is that the training programs for the displaced workers should be realistic about this situation and consider other alternatives. Policy options to help displaced workers in mature industries to relocate for the sake of finding jobs in high technology industries elsewhere are not likely to be effective, for the two kinds of industries coexist in some regions like Michigan and the the cross-industry movement of workers has been minimal. Another implication is that job security agreements should be instituted so as to allow time for the competitiveness increasing effect to generate jobs.

Manufacturing Infrastructure

When the U.S. semiconductor companies began moving their labor-intensive assembly work overseas to low labor cost countries, it was not anticipated that eventually a substantial portion of the manufacturing infrastructure would be gone with the move. The declining manufacturing capabilities of the U.S. can be attributed partly to this loss of the infrastructure. This lesson should be learned by other industries as they consider overseas outsourcing.

On the other hand, as discussed previously, the promising future for U.S. manufacturing seems to lie in the direction of making customized high value-added products. A new kind of manufacturing infrastructure, including the necessary human resources, can be developed and maintained to keep the U.S. competitive in this sector of manufacturing. There are certainly policy implications in terms of incentives to facilitate and accelerate the building of the rew infrastructure. A question which seems worthy of additional study is whether the pattern we have observed in the semiconductor industry of onshore production of customized products and offshore production of commodity products is becoming pervasive across manufacturing. If so the labor market patterns observed in vision and microelectronics would become more universal in the U.S. -- production users will be displaced by software engineers and physsical capital.

In this transformation of traditional manufacturing, can the U.S. maintain a leadership position? Are there enough incentives for the U.S. firms to stay in the business if they cannot compete well in the production of standard products? While there is no consensus on these issues, many U.S. firms are positioning themselves to focus mainly on the technologically sophisticated and customized products. This may still be beneficial to manufacturing employment. The alternative of becoming a technological follower has the cost of still greater employment losses. As an illustration, one manufacturer we spoke with indicated that reliance on foreign manufacturing equipment has the drawback that the manufacturers in the source country typically have a 2 to 3 year-lead in manufacturing technology. For reasons of national or company policy, the home country appears to receive a substantial lead in access to the best available technology.

Our discussions with several manufacturers indicated that the U.S. has such a cost disadvantage in many manufactured components of vision and robotic systems that even the dramatic depreciation in the U.S. dollar from 1985 to 1986 has not been sufficient to rationalize domestic production of these components. What this suggests is that vision systems alone, or for that matter vision systems in combination with flexible manufacturing technology, may not be sufficient for the U.S. to regain competitiveness. Only a full scale effort, involving these elements as well as worker training, support of engineering education and favorable tax laws will be sufficient for the U.S. to remain a worldwide manufacturing center.

Geographic Concentration

High tech industries have tended to concentrate in a few geographical locations. It has been pointed out that the existence and quality of research universities and transportation facitilites are important conducive factors to retain, if not attract, high tech industries (Jarboe, 1983). The conventional wisdom has led so many states and regions to use similar approaches and offer similar concessions to attract industries that they almost offset one another. What might be more effective for each region as well as more desirable for the whole nation is for each region to develop differentiated strategies and policies that are based on their inherent comparative advantages -- unique natural resources, historical heritages, long established industrial and commercial activites, etc.

Immigration Policies

The globalization of high tech industries has manifested itself in the form of international joint ventures and the growing role of certain developing countries. This results in an increasing flow of foreign workers coming to the U.S. as well as U.S. citizens moving overseas, some temporarily and some permanently. Also,an increasing fraction of the engineering graduate students, especially at the Ph.D. level, in the best U.S. universities are foreign students. Many of them have chosen to stay in the U.S. after they graduate and eventually become naturalized citizens, bringing a part of their families to this country. There is a need to understand the size and the composition of these immigrants, and there is a policy issue as to whether and how to differentiate them from other kinds of immigrants.

Incentives for Technology Development

An issue facing policy makers is whether there are adequate incentives for the U.S. industry to develop new technologies like machine vision. It appears that it will lead to major labor market transitions but seems critical for allowing U.S. manufacturing to compete internationally. If one envisions an industry's learning curve which has company and country-specific components, then there may be adequate incentives for domestic firms to bring onto the market new products and software since their investment can be recovered by future sales. However, if a technology cannot be patented and can be replicated by other companies and in other countries, we may see insufficient development. Perhaps the perception by many informed people that by 1998 over half of machine vision industry's sales will be from imports is having a discouraging effect on longer term product development. This anticipated loss of future market share can be very costly if the firms respond by focusing only on short term goals.

Planning Horizons

Another related issue bordering on industrial policy debates has to do with planning horizons in different institutions in different countries. We have been told by interviewees that they are concerned about the relatively short planning horizons and objectives of the U.S. firms, whose chief executive officers tend to think ahead only 4 1/2 years on the average. Even the venture capitalists are not very patient, wanting to liquefy their investments in 3 to 5 years (Business Week, 1986). In contrast, foreign firms and agencies such as Japan's Ministry of International Trade and Industry (MITI), have a 10-year or longer planning horizon. The end result is that most U.S. firms insist on a 20 percent or more return on investment, making long-range investment in advanced manufacturing technology such as flexible manufacturing systems, including advanced application of machine vision, difficult to justify. In contrast, many Japanese firms, with a goal for long-term stable growth, emphasize quality, delivery, and keeping people employed, and are satisfied with 1 to 2 percent profit in the short term.

Many observers we talked to expressed concern that manufacturing industry in the United States is making a "graceful exit" because of the perception that they are unable to earn high target returns on investment. In this pessimistic scenario, investments are targeted on success for the expected duration of top mangement's tenure rather than longer term health of the firm or industry. It is our belief that public policy to support basic engineering and training as well as tax policy can lead to appropriate incentives to lengthen planning horizons of basic institutions in the U.S.

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APPENDIX B A STYLIZED PICTURE OF THE MACHINE VISION INDUSTRY

The machine vision industry is in its early phase of development. There are now many firms trying to succeed in this market. There is a wide range of technologies within the field of machine vision and most applications are specialized to the particular needs of the user. The industry is heavily dependent on a highly trained workforce: in many companies engineers represent at least half the employees. Few companies are currently profitable and are sustained by venture capital or financing from larger corporations.

(1) What industry insiders foresee is a clearer definition of markets in the next 5-10 years, greater use of standardization (though with different technological or scientific foundations dependent on end use).

(2) Informed people also anticipate a decline in cost of purchase and operation of vision systems, a linking of vision systems to the overall factory computer network, and a standardization of software (MAP as an example) with more of the software based on chips dedicated to vision systems.

(3) The industry itself is expected to grow by a factor of 10 in the next 5 years, with a substantial diversification of applications such as surface-mounted devices (SMD) inspection, food processing, and three-dimensional (3-D) guidance of robots.

(4) The industry customers (manufacturers) are expected to make much greater use of skilled blue collar workers but the vision firms will still be heavily dependent on engineering talent and the rapid growth should lead to more employment in the industry itself.

(5) One of the main forces encouraging use of machine vision, international competition, is seen as a major element in supplying the U.S. market in the next 10 years.

(6) Cost reduction via vision technology is seen as bringing "on-shore" some activities previously sent overseas.

(7) The industry will continue to be quite concentrated geographically in several locations throughout the country even as the range of applications for machine vision increases.