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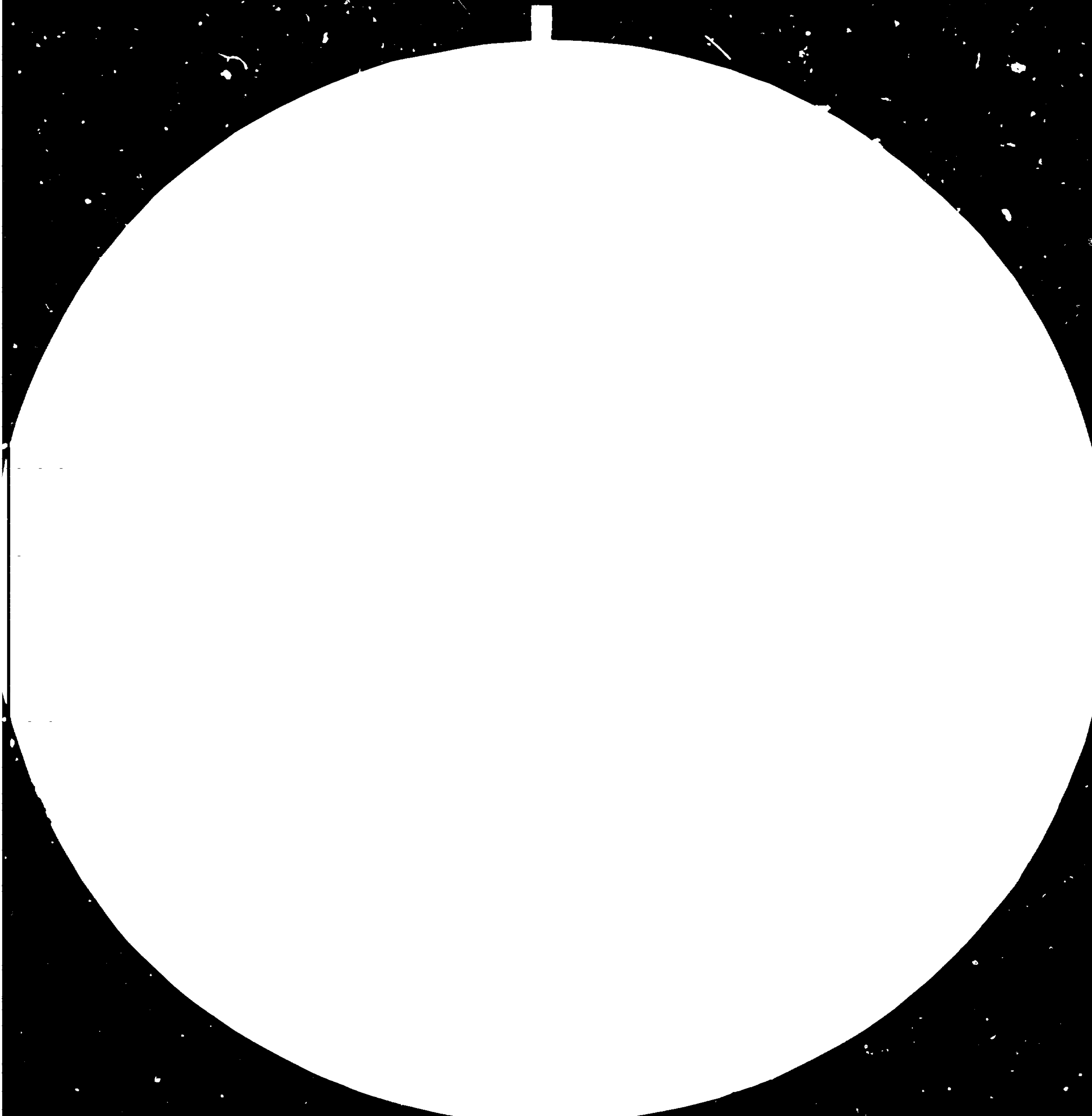

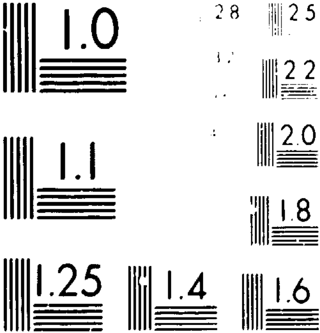
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# MICROPROCESSORS AND PRODUCTIVITY: CASHING IN OUR CHIPS*

by

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When complete transistor circuits were first diffused onto silicon chips in the late 1950s, it became possible to add "intelligence" to products and processes. In practice, however, the high cost of custom designing chips for specific applications made them a practical addition only for mass-volume products such as watches and pocket calculators, or for applications where the value added was sufficient to justify the high cost.

Then in 1969, M.E. Hoff, an engineer for Intel Corp., began searching for an economical way to produce calculator chips and found he could incorporate the entire central processing unit of a computer onto a single silicon chip, thereby creating the world's first microprocessor. By attaching a few additional chips to supply other basic functions such as memory, he had, in effect, created a tiny programmable computer. This seemingly simple development launched a virtual revolution in machine intelligence.

Standard chips could be mass-produced and then tailored to specific uses by adding the appropriate programmed instructions, making "intelligence" available at low cost for virtually any application, however unique. And unlike other programmable devices - computers and minicomputers - microprocessors were not limited in their application by size, complexity, or power consumption.

In its own way, the microprocessor is as revolutionary as the wheel, the combustion engine, and the light bulb, because it has the potential to effect major changes in our quality of life. By 1978, microprocessors were being made by some 41 manufacturers offering more than 150 different models.

Microprocessor applications now span almost every basic area of our lives — from transportation, manufacturing, and medicine, to recreation, education, and homemaking — bringing about changes for both manufacturers and users.

The potential social and economic implications of widespread microprocessor use, particularly with respect to employment, are viewed with growing apprehension in many countries. In Australia, microprocessors have been dubbed the "job killers." In Great Britain, a television show entitled "The Chips Are Down" portrayed the microelectronics era as a period of widespread job loss and economic upheaval, leading one member of Parliament to propose a ban on the import and use of microprocessors except under strict governmental control. Even in the United States, where people are more accustomed to mass applications of electronics, there is apprehension over the economic and social consequences of microprocessor applications.

The high level of concern in Great Britain led the British Department of Industry to fund a study, conducted by M.I.T.'s Center for Policy Alternatives, to examine the impacts of microprocessor use in existing applications in the United States. Eight products were selected for detailed study: heating, ventilation, and air-conditioning controls; automobile ignition sytems; word-processing devices; electronic postage scales; optical inspection systems in manufacturing; medical equipment; monitors for hydraulic cranes; and electronic sewing machines.

These products represent a range of applications in which microprocessors were used to enhance the performance of existing mechanical products. All were considered highly successful applications from a technical standpoint. Some were new products, radically different from anything previously available. Others were essentially an extension or enlargement of a firm's existing product line. In one or two cases, the microprocessor simply replaced many mechanical parts at reduced cost and with more reliable control. In other cases, the use of microprocessors resulted in a revolutionary change that opened new horizons for the product manufacturer.

The study examined each application from three points of view: What motivates the use of microprocessors? What is involved in generating a successful microprocessor-based product? And what are the impacts of microprocessor applications on producers, users, job skills, and employment?

## The Advantages of Intelligence

Microprocessors can enhance the performance of an enormous range of products. They enable machines to compute, store information, communicate with their operators, control and time various events, sense physical parameters, and perform a host of other functions. These capabilities are combined to increase the flexibility, capacity, convenience, speed, safety, and reliability of an existing product and to lower operating costs.

In the field of written communications, for instance, microprocessors have transformed typewriters into highly sophisticated "word processors" that enable operators to type in, store, and manipulate information displayed on a screen before printing it out as final copy. A variety of functions such as pagination, centering, duplication, deletion, reorganization of material, and correction can be performed literally at the touch of a button.

Automobile manufacturers have begun to use microprocessors to regulate engine performance to reduce undesirable emissions, improve fuel economy, and control safety features such as brakes and airbags. Microprocessors are being used in all types of buildings to conserve the energy used in heating, ventilation, and air-conditioning systems through automatic control of start-up, setback, and peak-load limitations. And the incorporation of microprocessors into postage scales has greatly increased the accuracy and efficiency of postage calculation, saving thousands of dollars in postage and labor costs every year for firms that use them.

From the manufacturer's point of view, microprocessors offer considerable advantages as well. For instance, microprocessor-based logic circuits generally require far fewer chips than custom-designed circuits. For a simple application, a microprocessor may reduce the number of chips from fifty to two or three, thereby reducing the associated cost of packaging, circuit boards, power supplies, and space.

Microprocessors also replace the task of hardware design — the selection and interconnection of many components to produce custom-designed logic circuits — with software design, which involves writing, checking, and assembling computer programs. The resulting efficiencies make possible the relatively low cost of microprocessor applications.

Substitution of software design for hardware design also simplifies the job of engineering and designing new products. Laying out, testing, and debugging even moderately complex random-logic hardware can be very time consuming. By contrast, a software designer can shorten the time needed to program a microprocessor in various ways. Errors can be corrected by executing a simple program change rather than rewiring or redesigning a custom circuit. The efficiency of software design is enhanced by "development systems" that translate high-level programming languages such as Fortran into machine language for the microprocessor — a tedious and costly task if done by a human programmer.

Once the product has been manufactured, subsequent modifications and improvements can be made simply by altering the stored program — the production process scarcely needs to be touched. Products can be specially tailored for individual users through changes in the software. And once systems have been installed, software designers can make changes over telephone lines or mail new chips to product users at modest cost.

Microprocessor programs can also include testing and diagnostic routines that make it easier to use and repair the product and warn users about machine malfunctions. Microprocessor-based machines can monitor and regulate the accuracy of their own or operators' performance by comparing information about actual performance — obtained through measurement, calculation, or operator input — with fixed values stored in the memory. If discrepancies are detected, the machine can take corrective action, sound an alarm, or shut itself down.

Servicing is generally enhanced in microprocessor-based products. Simple repairs can be effected immediately — sometimes over the telephone — and operation restored without delay. Faulty modules can be readily removed and replaced. Certain products can even be programmed to lead the user step by step through simple diagnostic and repair procedures.

## A Load Off One's Mind

Microprocessors enable a product to interact with its users in simple ways. This makes the product easier to use, shortens the time needed to learn how to use it, reduces operational errors, and makes the results more consistent. Users experience fewer failures because microprocessors can forestall obvious mistakes in control and operation. Thus, microprocessors can be used to enhance safety and operator performance. A particularly striking example of this among the microprocessor applications studied by the Center for Policy Alternatives is the Eaton Crane Load Computer.

Conventional hydraulic cranes require a high degree of operator skill. Safe tolerances in any given situation depend on the configuration of the crane itself and the load. Conventionally, a load chart for each crane is posted in the cab to help the operator work the crane safely, and instruments read out critical variables such as the angle on the boom and the tension on the lines. However, because of the complexity of crane operation, operators normally rely on experience and intuition to maintain safe performance.

Technical requirements vary enormously among cranes and loading situations, making the design of a suitable device exceedingly difficult through traditional approaches. In addition, the use of more than a simple monitor is still discretionary in the United States, which sets a modest limit on the price that an operator is willing to pay for such devices. These conditions make crane monitors an ideal application for microprocessors.

The Eaton Corp., a major U.S. capital equipment manufacturer, has developed a highly flexible microprocessor-based monitoring system that can easily be adapted to each machine and application through programming and data supplied by the operator. The same hardware can be used for all installations, with a single microprocessor programmed to compute the appropriate variables. Constants such as the load chart for a given crane are stored in the microprocessor's memory, and situation-specific parameters are introduced by the operator via a keyboard and display in response to a series of questions posed by the instrument itself. Using the input data, the microprocessor then computes safe operating parameters, such as boom accelerations and hook load, to great accuracy. In addition, the Eaton device allows the operator to set a variety of constraints on machine function -- to avoid striking a wall or power line, for example — or to operate safely without actually seeing the load on the hook.

Because safety is critical, the Eaton system includes several features to ensure reliability of every aspect of its operation. Values given by the operator are checked to make sure they are within a fixed permissible range, and self-calibration routines continually test the accuracy of the microprocessor calculations.

A major limitation of any such electronic instrument is the brutal treatment involved in crane transportation and use. Earlier electronic devices failed because the parts were shaken to pieces from vibration, shock, and pounding. However, the microprocessor-based monitoring instrument console is compact enough to be removed for separate transport.

The Eaton system was developed when the firm's technical management, recognizing a need to attain competence in using microprocessors and electronics, chose the Crane Load Computer as a means of strengthening their existing product line. Visits to crane manufacturers made it apparent that an "intelligent" and refined product was required. One engineer was assigned full time to the project, and he carried out the development and testing of the device with the part time help of one mechanical designer and one programmer-engineer. The design work was essentially completed in 18 months.

The electronic monitoring system was developed over a three-year period through intimate contact with a major crane manufacturer, and it has been tested in several installations. Initially, experienced crane operators were skeptical of the apparent complexity of the keyboard input and instrument display, but the value of the instrument to their own safety and effective operation became apparent once they used the machine. Modifications are continually made in response to users' suggestions through changes in the software rather than the hardware design.

The success of a commercial version of the Eaton device has yet to be determined. It is likely to be cost-competitive with other complex monitoring devices, but because the Eaton system has remarkably superior performance, its market potential may be high compared with other products currently available.

## A Stitch in Time

The Athena 2000 — Singer's revolutionary electronic sewing machine — is another excellent example of the application of microprocessor technology. Introduced in 1975 after four years of secret design and development, the Athena 2000 is a highly flexible instrument, programmed to perform 25 different stitches at the twist of a dial and the press of a button. The change from an electromechanical machine to an electronically controlled machine has simplified the operator's task while retaining the sophistication of the most advanced mechanical models.

To develop the Athena 2000, the project manager and a core group of about eight engineers stayed with the project from inception to first production, working in secrecy. Electronic parts were purchased through another Singer division to disguise the fact that the sewing-machine division was interested in electronic components.

Formal work on the machine began in mid-1971. A major bottleneck in the development effort was in marrying electronic controls to mechanical parts. In conventional machines, the mechanical assemblies are driven by an electric motor with sufficient power to overcome minor friction from such common occurrences as tight fits and burrs on parts. When these mechanical linkages were driven by linear servos that were in turn driven by power transistors, excessive friction in the system caused the transistors to overheat and burn out. This difficulty carried over into production start-up, where more precise standards had to be imposed on mechanical parts.

The Athena 2000 was introduced as Singer's top-of-the-line machine at a price of $900, well over that of a comparable mechanical sewing machine. It was an immediate success despite the fact that it was introduced during a time of slumping sales in household appliances. Singer has introduced several other electronic sewing-machine models since the Athena, capturing an estimated 5 to 6 percent of the 1.8-to-2.0-million-units-per-year domestic sewing-machine market. Although the unit volume does not constitute an appreciable fraction of the market, the significantly higher prices of the electronic machines make the dollar share quite respectable.

The revolutionary design change apparently caught Singer's competitors by surprise. No comparable machine has yet been introduced by a competitor, and Singer has been able to enjoy at least a five-year advantage to recover its initial investment and bring its manufacturing costs down in preparation for competition.

The electronic sewing machine has had notable impact on various aspects of Singer's operations and its competitors. The advent of the Athena 2000 entailed changes in manufacturing processes, locations, work force, and management. The switch from electromechanics to electronics enabled Singer's engineers to remove approximately 350 mechanical parts from the 700 moving and nonmoving parts in a conventional machine. This resulted in significant changes in the manufacturing process: overall workspace requirements, capital equipment costs, settings and adjustments required during assembly, and overall production time were reduced. These changes shortened manufacturing start-up time and improved product quality. Similar changes in parts and assembly processes reduced manufacturing time and work-in-process inventory, but the higher value of raw materials and purchased parts tends to cancel any reductions in capital. Furthermore, because components are more specialized, the number of suppliers is reduced, so that Singer is now more dependent on its suppliers and consequently is vulnerable to delays and price increases. Also, the levels of worker skill needed to make the electronic machine are clearly lower than those required for electromechanical models, with more people in light assembly and fewer in machine operations and setup.

In supervision and management of manufacturing, on the other hand, the required skill levels have risen, particularly for analytical skills to diagnose intangible problems. Buyers for the firm also needed to become more sophisticated because parts once made by the firm have been replaced by electronic components purchased from outside. Field personnel needed to be retrained to handle the new machines. Training aids now consist of tabletop simulators displaying machine functions and interconnections. Servicing requirements have been reduced because the Athena is more reliable than its mechanical precursors. Service personnel are given diagnostic aids only, and field repair of electronic components is restricted to removing and replacing printed circuit boards. Faulty modules are returned to the factory.

Altogether, introduction of the Athena has apparently reduced total employment. However, the reduction is probably much less than would have occurred if the Athena had not been introduced. Singer has kept manufacture of the top-of-the-line sewing machine in the United States, thus preserving many domestic jobs that would have been lost to competing foreign imports or offshore manufacture.

The success of the microprocessor-controlled sewing machine had at least a temporary rejuvenating effect on the company. The machine contributed substantially to profits when other lines were experiencing a profit squeeze. Start-up was accomplished with only moderate capital investment compared with the capital necessary to develop a new mechanical machine.

It is unusual for an established firm with a 100-year tradition of evolutionary change to develop a product so radically different; the climate within such a firm normally works against such attempts. A key factor in success was the firm's decision to protect innovation from in-house reactionary influences by isolating the Athena 2000 team from the rest of the firm. By making the team self-sufficient from inception to implementation, and by giving it direct access to top management, the company effectively bypassed the internal resistance that the project normally would have encountered.

### Winning Strategies

Total development costs, tooling, and start-up expenses for the Athena 2000 were on the order of $10 million for the four-year development period — a relatively modest investment for a radical departure from a firm's traditional product line. In fact, virtually all the microprocessor applications studied by the Center for Policy Alternatives required relatively modest investments of labor, time, and money. In every case, engineering development teams were small, ranging from two or three people to no more than twenty. Support staffs were likewise of moderate size.

Microprocessor-based products generally took less time to develop than mechanical products because electronic components are normally shelf items. Tooling time for items such as printed circuit boards is short compared with lead times for machines, tools, dies, and fixtures for fabricating mechanical parts.

The financial investments for microprocessor applications were low. Typically, microprocessors are being applied to existing products, so while the change in product performance may be revolutionary, the effect on production processes may be minor. Where standard electronic components are used, only assembly and testing processes may be affected. Little is needed in the way of new assembly equipment, and electronic test equipment tends to cost less than traditional production machinery.

Certain design and manufacturing strategies appear to be important for successful product development. Where the microprocessor application is a radical innovation to an existing product line, as in the case of the Athena 2000, the project needs the strong commitment of top management and isolation from the rest of the firm during the incubation period. This is as much to protect the new idea from negative thinking within the firm as to avoid premature leaks to competitors. Where the application is not in direct competition with existing products of the firm, or where the application is an evolutionary change — for example, microprocessor controls in microwave ovens — this principle may still be useful but less crucial to the success of the project.

The development team for each product studied included two key people. One, the "design integrator," had substantial knowledge about the product or process to which the microprocessor was being applied, expertise in several technical disciplines, and some understanding of electronics and microprocessor technology. The other key person was a "creative programmer," who was responsible for the efficiency, versatility, and reliability of the microprocessor programs. Careful programming contributes to the long-term success of the product by adding to its performance capabilities or reducing its cost.

One successful design strategy in several applications was to place the sophistication of the product in the microprocessor memory rather than the mechanical components. Changes in tables, parameters, or programs then become the mode for rapid, low-cost future modifications.

The greatest design difficulty in microprocessor applications appears to involve the interfaces between the microprocessor and the mechanical parts of the product. Designing sensors and actuators — the components that inform the microprocessor of the state of affairs and carry out the microprocessor's commands — is a particularly demanding task. Good design depends on an intimate knowledge of how the product must perform. This may explain why many of the firms we studied preferred to train existing technical personnel in electronics rather than bring in microprocessor experts and acquaint them with the product and users' needs.

A general marketing strategy has been to introduce the microprocessor-controlled product as a top-of-the-line item. This is a logical approach where microprocessors enhance product performance and provide greater value to the user. The greater profit margins normally found in the higher-priced items help to repay development costs, while prices tend to limit demand as the firm is building production capacity and correcting deficiencies. In the long run, however, many microprocessor applications will result in less costly products and price reductions when competition develops.

Although evidence is quite limited, it appears that the application of microprocessors in one product line may be a company's first step into a series of new market areas. Once a firm sees that the functions performed by microprocessors in one application can be readily transferred to products for other markets, it may be able to diversify its product line, a decided stimulus to innovation.

## Microprocessors and Jobs

Microprocessors can have dramatic effects on workers' job content, location, and employment levels in all aspects of product manufacture and use — from production workers, supervisors, and engineers to inspectors, maintenance technicians, salespeople, and service personnel.

Manufacturing operations are likely to undergo substantial change, with expanded requirements for light electronic assembly, reductions in the production of mechanical parts, and a shift from final mechanical inspection to in-process electronic testing of components and assemblies. This entails changes in job skills as well. For example, production and service jobs tend to be deskilled when metal-working jobs are replaced by simpler light electronic assembly. Engineers' and supervisors' jobs, on the other hand, tend to become more demanding. As devices become more sophisticated, training and retraining requirements will increase.

The employment effects of microprocessor applications tend to be hidden. A shift in job contents within a single firm may actually cause simultaneous layoffs and new hirings. The labor used per unit of output may decrease, but market expansion obscures this fact by requiring greater employment on the whole. And the loss in market share by a competitor may result in layoffs elsewhere. This combination makes it difficult to determine which effects are specifically attributable to the advent of a product using a microprocessor.

In the short term, the firms we studied tended to experience higher employment, probably because of increases in market share or general market expansion. The longer-term effects are less clear. As a firm goes from rapid changes in product line to a period of consolidation and standardization, increases in output may well be possible with no further increases in employment. Furthermore, as competing firms develop similar products, the employment increases of early entrants may prove temporary.

In our study, employment in the firms *using* microprocessor-based products was either unchanged or reduced. Half of these firms reported greater worker productivity but no reduction in employment levels, at least in the short term. A few user firms experienced productivity increases of one-third or more and some reductions in employment. In several instances, operators' work shifted to maintenance and monitoring tasks — keeping the device running smoothly and checking its output.

It seems likely that the more important employment effects will involve firms that retain conventional technology. These firms may experience a reduction in employment or a curtailment in growth as their competitors' microprocessor-based products capture larger shares of the market. More seriously affected may be those firms making parts such as conventional control systems or timing switches that perform functions that can be handled more elegantly with microelectronics.

It also seems likely, based on our examination, that the demand for software for microprocessor applications will create a substantial number of programming jobs. A billion dollars worth of programming material has already been created for one microprocessor, the Intel 8080. It is quite possible that the total value of application-and-development systems and software sold by suppliers and service firms will ultimately exceed the value of the microprocessor chips themselves.

Straightforward microprocessor applications are occurring rapidly today. Entry costs are low, capital requirements are modest, and products can be designed relatively rapidly and inexpensively. Firms entering this market have available more standardized parts and more powerful tools than earlier firms. These factors may explain why it has been easy for small new firms to break successfully into existing markets with innovative products. How long this strategic window will be open remains to be seen. As more advanced microelectronics become available, as the emphasis on software and tailoring products to customers' needs increases, and as simpler applications are completed, a firm will need more sophisticated system designs, software, and production capabilities to compete successfully. Entry costs will surge. Firms entering late could be at a serious disadvantage compared with companies that have already begun to develop skills and understanding of this new technology.

Competition has traditionally been limited by the need for large investments in equipment for making parts, by the availability of highly skilled labor, and by long, expensive product-development periods. What will happen now that products can be more easily and efficiently assembled with different combinations of standard modules? Some manufacturers have speculated that product life may be markedly shortened by the advent of microprocessors, thus requiring more rapid payback of development and tooling costs. Indeed, some firms have tried to protect their positions by building more flexibility — extra keys or buttons, for example — into their products and systems than is immediately needed.

By the same token, microprocessors are reducing the opportunities for product differentiation. If the same microprocessor chip is used in the least expensive sewing machine as in the most expensive one, then features of the most expensive equipment can be provided on the least expensive model at relatively modest cost. As the need disappears for more or higher-quality parts that previously distinguished more accurate and expensive products, how will premium items be made distinct from utility models?

The rapidly increasing application of microprocessors to products and processes will certainly affect competition, which will probably increase from many unexpected sources. Wherever they appear, microprocessors will make the competitive world of the future less certain, less comfortable, and far more exciting.