OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

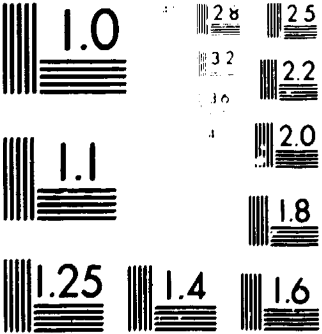
FAIR USE POLICY

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org



MICROCOPY RESOLUTION TEST CHART

11430

Distr.
LIMITED

ID/WG.372/1
3 May 1982

ENGLISH

United Nations Industrial Development Organization

UNIDO/ECLA Expert Group Meeting on Implications of Microelectronics for the ECLA Region

Mexico City, Mexico, 7 - 11 June 1982

PROSPECTS OF MICROELECTRONICS APPLICATION IN PROCESS AND PRODUCTS DEVELOPMENT IN DEVELOPING COUNTRIES *

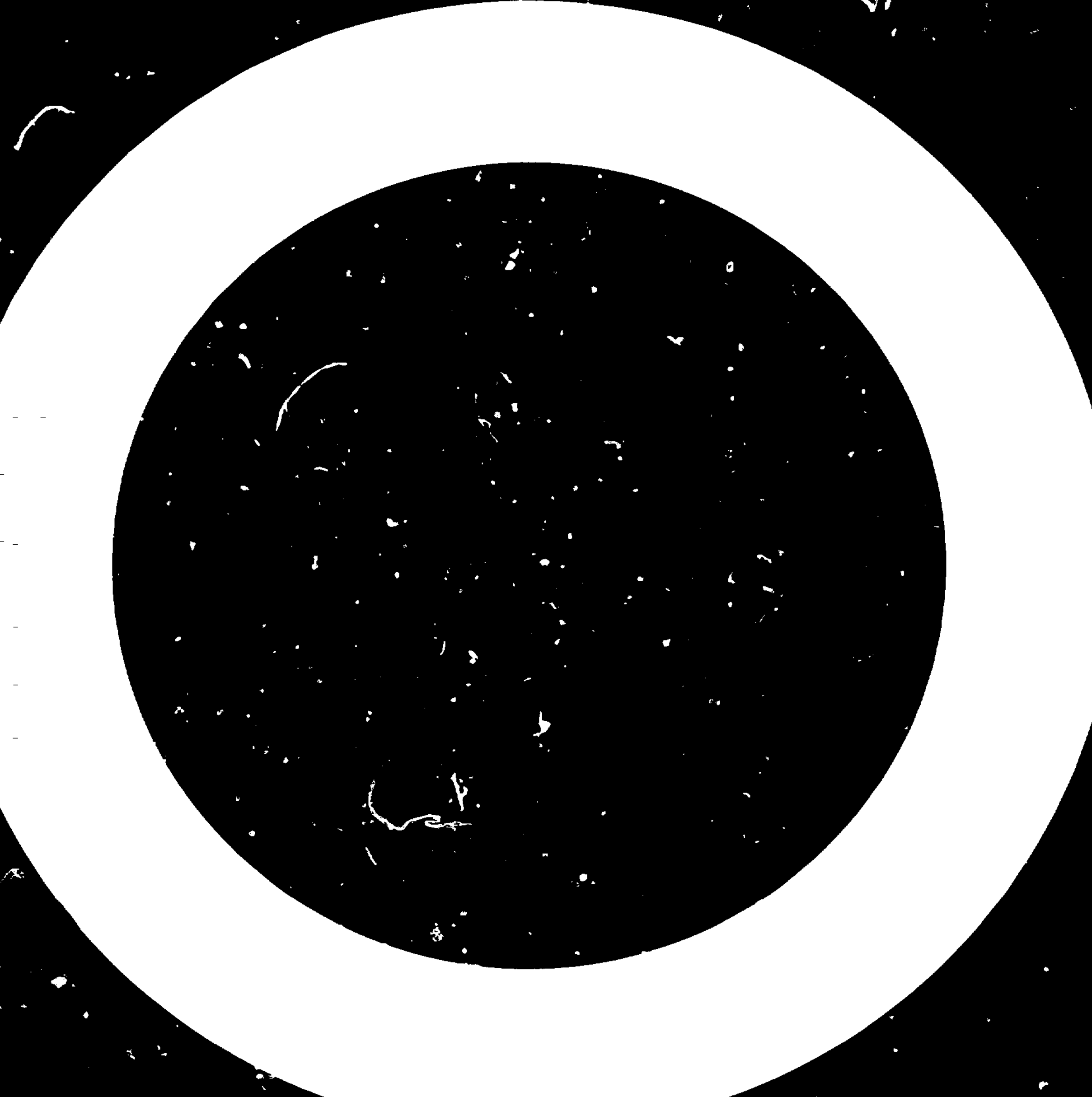
by

Michael Radnor**

* The views expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

** UNIDO Consultant.

V.82-25400



SUMMARY

1. With electronics already critical for development, advances in microelectronics, especially microprocessors, make developing countries involvement in microelectronics revolution inevitable. Many of the products and processes used in developing countries will contain microprocessors in the future, requiring at a minimum, the capability on the part of the operators to use and main them in appropriate systems. In addition, recent advances in microprocessors have given this technology precisely those characteristics that make it appropriate for use in developing countries. By putting the computing power of a large main-frame computer on a chip costing just a few dollars, by making these chips cheap and easy to use, and with skill requirements predominantly in software programming capability, microprocessor utilization comes well within the reach of developing countries. The microprocessor has opened the door to a vast array of needed applications, applications which can help overcome one of the greatest problems of developing economies: the shortage of trained middle level technicians and analysts. By training people to be skilled in identifying applications and in designing the necessary software, developing countries can generate an enormous multiplier effect in the skills area. Contrary to some of the conventional wisdom, microprocessors can actually work to the comparative advantage of the developing countries .

2. Developing countries should be looking to this area of electronics rather than attempting to tread the path already taken by the countries of South East Asia. It would be a major error to try to compete in mature sectors such as television, radio or calculators, or in those fields dominated by capital-intensive, closely controlled production systems, such as video cassettes.

3. In contrast, simpler microprocessor-based information and control products have a number of very desirable features. They can be made cheaply from standard, off-the-shelf components which can then be customized by the user. Products can be very reliable, less sensitive to harsh environments and hard use, more serviceable and smaller. These products are easier to develop and easier to expand modularly, and they are better able to withstand inadequacies in other systems, skills and materials. They facilitate small scale decentralized operations. They should not be confused with more complex information processing systems such as the small personal or handheld computers, which are more demanding of technical skills in their use. A key insight is to recognize that in the microprocessor the high technology is put in by the manufacturer; their use requires relatively low skills.

4. It is essential that developing countries gain control over this appropriate technology in time to cope with the inevitable involvement, however reluctant, which will be induced by imported products. Even more significant is the opportunity to control the applications of microprocessors in developing countries and to use them advantageously as a means to develop indigenous economies. The appendix to this paper describes several illuminating examples of products that can be manufactured using microprocessors which can have dramatic consequences in such sectors as industry, energy, transportation, food processing, agriculture and health care. However, these suggested applications

since they still reflect developed country experience, do not scratch the surface of the potential applications that this electronics automation revolution will make possible in developing countries. By becoming knowledgeable and involved in this advanced, but easily adopted, technology now, developing countries can leap-frog their current technology gap and land positioned for the electronics world of the future.

5. The costs of adopting microprocessor technology are relatively low. Chips and other components continue to drop in price, and those needed for developing country applications tend to be of lower memory capacity and therefore cheaper. Assembly costs will be less than with comparable non-microprocessor electronics products, and software for relatively simple devices will tend to be inexpensive. The costs of developing expertise to create software, to develop systems, and for maintenance and service are not prohibitive, and have long-term payoff in upgrading skills. An educational and communications infrastructure will be necessary to build this capability.

6. The strategies recommended for facilitating the use of microprocessor-based products and processes in developing countries are primarily bottom-up or user pull, relying on carefully identified user needs and current practices within existing applications, later extending to less familiar domains. The approach would be to build out from existing institutions, programmes and expertize, while linking to relevant technology suppliers and to manufacturers in other developing as well as developed countries in possible joint ventures. The goals would be to build up self-sustaining capacity through training of trainers, accumulation of experience and confidence among users through model applications, and a rapidly accelerating second phase large scale effort to maintain timely advantage in a rapidly-developing technology. A suggested agenda for achieving these goals is outlined.

. These strategies must be pursued with a full awareness of the difficulties, costs, time requirements and the political and broad economic implications as well as the benefits and opportunities. In particular developing countries must ensure that programmes to be carried out will provide them with the sought-for benefits without entrapping them into conditions of costly dependency.

1. ELECTRONICS IN DEVELOPING COUNTRIES

7. Already of central and accelerating importance in every aspect of life in the developed countries, electronics is destined to be one of the determining factors in the rate of expansion in developing countries Inevitably, development will bring with it increased involvement with products and systems utilizing advanced electronics--in industry, transportation, health, agriculture, the village, the home, and every other sphere of social endeavour. Some parts of this involvement will be induced without choice. Automobiles, machine tools, consumer products, information processing systems and much else that we use and do now contain such electronics and these will become even more electronics-intensive in the future. The expanded use of such products, processes and systems requires developing countries to have the capacity to be in full control of how they are developed or selected, and to ensure their proper use and maintenance. This demands the build-up of a trained capacity and infrastructure.

8. Beyond this induced effect, major autonomous opportunities for enhanced development will become available through the application of advanced microelectronics. New and improved products and processes will become available to better utilize such scarce resources as capital, energy, materials and high-skill labour, so vital to industry, transportation, agriculture and other key sectors. Also, the opportunity to enter into production in new technology fields and/or at low scale will become possible for developing countries through the exploitation of microelectronics technologies which permit better process optimization and control, faster set-ups and change-overs (allowing for efficient small-lot production levels).

9. In the more developed, and even in some of the newly industrialized countries of South East Asia and Latin America, the capacity to exploit this electronics revolution has grown on the shoulders of a tradition of several decades of electronics manufacture and use. Developing countries technological position in electronics is far less favourable. By contrast, a recent ESCAP survey of electronics in South East Asia evidenced a growing capacity for the manufacture of electronics components and products (but not in microelectronics applications), in nations as varied as Bangladesh, Thailand, Malaysia, Singapore and Pakistan. A comparable technology base is lacking in many developing countries, but the nature of technological development in microelectronics in recent years has made it more feasible to enter the field at this time than at any previous point since its inception. The technology has become easier and cheaper to exploit at the application and user levels.

10. Facing an explosive revolution in terms of the complexity and variety of available microelectronics componentry and systems, those who fail to become involved now will face a much more difficult challenge in the future and consequently, a much greater likelihood of finding themselves locked into a condition of dependency. Those who do enter now will be much better able to control the direction of technology development for their own appropriate use and benefit. The implication for developing countries is that steps should be taken expeditiously to prepare for this new technology and ensure their proper role in microelectronics as an element in their strategies for technological development.

11. While this historic necessity for developing nations to become meaningfully and appropriately involved in electronics is virtually self-evident, the nature of such an involvement is too frequently misunderstood. It is simply not true that any kind of involvement in electronics technology is "a step in the right direction". To the contrary, it is easy to fall into the trap of setting up inappropriate electronics sectors. More specifically, certain nations do not need to reproduce the electronics development pattern of developed or of other developing countries.

12. Electronics in its various forms and applications plays a large and growing role in our societies; in communications, entertainment, education, industry, increasingly in agriculture, etc. Naturally, nations are concerned with questions of control and of self-reliance with respect to these areas. Because of the large potential scale, there are also concerns, about the large outflow of precious foreign currencies to acquire the needed products. Unfortunately, the resulting import substitution strategies and the often associated protectionism has had less than fortunate outcomes in many (though not all) cases. The large scales involved are also viewed as great opportunities for employment, given the high labour content up till recently (but much less so now), and as export potentials with big value-added content. Such perspectives have provided a good basis for strategies for some nations at some points in time, in some areas of electronics. For others, they lead to a waste of resources and to ineffective, even totally impractical, strategies.

13. It is recommended that developing countries should not, with some exceptions, set up plants to manufacture products that must be manufactured in closely controlled plants to meet the cost and quality standards needed for international competitiveness, where the rates of change in technology are discouraging to a potential new entrant, and where well-entrenched competitors enjoy substantial market and production advantages. Such areas include electronics products and components as video cassette decks, complex calculators, integrated circuits, microprocessors, etc., that are currently manufactured in large volumes in Japan, the U.S., the Republic of Korea, Hong Kong and various other countries. Nor should they invest heavily in highly matured areas (such as black and white TV, simple radios) where cottage industries with easy access to cheap components can easily outperform formalized industries as product assemblers. Instead, they should seek to enter fields that maximize their own comparative advantage, their technological learning potential and their ability to serve their own national needs and those of their trading, regional and other partners. The recent revolution in microelectronics provides developing countries with a unique opportunity to leap-frog over their technological gap in electronics.

2. THE MICROELECTRONICS REVOLUTION

14. In a matter of two or three decades, the electronics industry has advanced its technology from one that required many individual, relatively large, costly and unreliable vacuum tubes wired up through complex, costly and unreliable circuitry to perform a given function; through a stage in which the tubes were replaced by individual small and eventually much cheaper and more reliable transistors (these were to fall in price from $100 to $1 by the late 1950's, in less than a decade); to the stage,

in the early 1960's, in which a large number of these individual transistor building blocks became integrated into logic blocks to build small and medium-scale integrated circuits. The change from vacuum tubes to transistors enabled the industry to go from a developmental (almost curiosity) phase of computer technology, to commercially viable large-scale computer systems with acceptable down-time characteristics, so spawning the main frame computer industry. It was this same level of technology that enabled the $1,500 to $3,000 four-function electronic calculator to be developed in the mid-1960's ("too little for too much"). The small-scale integrated circuit was to bring down the cost of such calculators to between $700 and $900, and launched the minicomputer and computer machine controls industries.

15. Just about the time the medium-scale integration technology had run its course, the very-large-scale integration using MOS or metal oxide semiconductor technology came about. This technology allowed the integration of entire functions into a single chip as used in the calculator, the machine control, display controls, etc. Now, literally hundreds of thousands of transistors could be integrated into a single chip to provide a functional block of a very complex nature, such as a calculator, typewriter or CRT terminal control. The problem was that each one of these special building blocks had a limited market because they were designed for specific functions, not useful to everyone and therefore the vast reductions in price which came from economies of scale simply could not take place. There was considerable concern in the industry at this time as to how to achieve the volume needed to make this technology viable and cost effective.

16. In the early 1970's, a large-scale integration chip was introduced that could be programmed to carry out an enormous variety of information processing and control functions, be mass produced and therefore, undergo the so-called learning curve and the price reductions that result from high tooling and high production. This was the Intel 4004 microprocessor. The initial microprocessors had the short-comings of all infant technologies. They were slow, stupid and very difficult to work with and programme, but the above cited advantages outweighed all of their short-comings and produced the microprocessor revolution. Since then, microprocessors have steadily become smaller, smarter, cheeper and easier to use. Coincidently, within a couple of years the factory cost of a simple calculator fell to $4 or $5 as the price of high volume, dedicated integrated circuits fell even further.

17. Consumer products (such as games) commercial products (such as copiers and word processors), and industrial controls (such as in machine tools), are now at the same threshold stage with respect to applications possibilities as was the semiconductor industry when very-large-scale integrated chips were developed. It is now possible, with microprocessors, to build special purpose products, machines and systems that can carry out an enormous range of functions, and at a very reasonable cost of development and production. And microprocessors are by no means the only area of significant recent advances in microelectronics. Voice chips, optical electronics, wafer chips too small to assemble by hand, and much more, are adding to an

arsenal of componentry that makes it possible to develop products, processes and systems which are very smart, easy to use and comparatively cheap for what they do, most reliable even under adverse environmental conditions, very fast, very flexible (they can be tailored to special needs, built up in modular designs and stages, etc.), small, and also low in energy consumation. Relatively speaking, such products and processes are also cheap and easy to develop and produce (compared to products using discrete components, for example). It is characteristics such as these that make modern microelectronics so attractive to producers of virtually any kind of product. It is these same features that make these new technologies especially "appropriate" for developing countries despite their "high technology" content.

18. The key insight is to recognize that the high technology is put into the chips by the semiconductor manufacturer and what is passed on to the user is simple and small. In this sense, it represents a fusion or synthesis between the emphasis on "appropriate" or low cost relevant technology and advanced technologies. Though among the most advanced of current technologies, the value of the current "micro" end of the spectrum of the electronics revolution is precisely that it permits the development of low-cost, small-scale, easy-to-use applications.

19. This must be contrasted with the situation at the other, or "macro" end of the electronics spectrum, where the introduction of large-scale, computer-based systems into enterprises requires in the first place, the setting up of a substantial infrastructure for training and technical support for maintenance, repair and assistance in programming and applications, together with systems design studies, etc. In looking at the applications of microprocesses, we are simply finding better ways to use a very novel, but cheap, type of general purpose tool, into the design of which a tremendous amount of research and development resources have already been poured .

20. Understanding this "counter-intuitive" nature of the microprocessor in particular is important for achieving its full significance for developing countries.The natural reaction that it must be inappropriate in developing countries because it is high technology is just plain wrong.The worldwide advent of the microprocessor is inevitable, but timing is critical if the developing world is to harness and control it advantageously.

21. This technological revolution makes available a confusing plethora of components, products and systems, giving the user the computational, information handling and control capabilities of main-frame, large-memory computers at a fraction of the cost. It is vital to distinguish among these, however.

22. At the "micro" level are the chips, the custom IC's, the <u>microprocessors</u> that can be designed and programmed to perform certain specified functions, as components in some products. These integrated circuits are always used in conjunction with other components in a circuit and it is in this "built-in" condition that they are interfaced with a user (or with other elements of a larger system). Even a microprocessor can be obtained as a single package or be an assembled multipackage of processor-related components (a central processing unit, the CPU; an arithmetic logic unit; time and control circuits; internal storage

registers). When a microprocessor is combined with the appropriate memories and input and output (I/O) ports, it becomes a microcomputer.* Some low end processors have combined a limited amount of memory and I/O capability in the same package to effect a single chip microcomputer system. A circuit design may include other kinds of chips (e.g., a voice chip) depending on the application. Whatever the architecture, we are still at the chip or multi-component level, to be incorporated into a device.

23. There is a major shift in level from these micro systems to that of the small personal and handheld computers, which we may call a small macro system. These small computers, word processors, etc., with their input keyboards, CRT and printer output terminals, and whatever else they need, may make use of a number of microprocessors to build up their required capacity. They are not to be confused with microprocessors or microcomputers, but frequently are. Somewhere between these small computers and microprocessors and microcomputers lie single board computers, and some microcomputers are capable of receiving more than one programme software package. The key difference, however, remains in the quality of the interaction between the processor and the source of the information inputs, as discussed above.

24. It is also possible to have systems made up of a series of micro and/or small computers linked together, feeding into a main frame computer. Such applications can facilitate the integration of many decentralized operations, each optimally planned and controlled and rationalized at a central planning and control location.

25. This micro/macro difference in function level has critical implications for the types of applications involved, skills and infrastructure required for development and use, and impact generated. In general, while the development skills needed with respect to the incorporation of microprocessors in products is high, that required for use of the products is low. By contrast, the personal computer comes as a ready-made package, but demands a high level of use skill. In both cases it should be noted that the basic skills required are those of programming (which is becoming easier) and, most importantly, of understanding the needed applications. As far as impact on productivity and employment is concerned, the arenas will tend to be different. The microprocessor impact is most likly to be seen in production and processing (in all sectors, e.g., health, as well as industry), enhancing productivity and reducing the need for intermediate level personnel (the semi-skilled checkers, controllers, analysers, etc.) and not much, as has been claimed by some, of the low skill level. If anything, the microprocessor is likely to provide developing countries with a comparative advantage viz-a-viz developed countries by helping to eliminate their shortage of semi-skilled workers and by reducing the incidence of errors and other problems caused by low-skill labour-intensive operations.

26. The applications of microprocessors come embedded in free-standing products or sub-assemblies which are new or improved (less costly and better performing). These are generally used to perform some productive, control or informational process such as a smart machine tool or irrigation system; a product or material inspector or analyser function (e.g.,

---

*Unfortunately, the term microcomputer is sometimes also used in the industry to refer to the small macro-level computers discussed in the next paragraph.

a blood analyser); as a device to control conditions in chemical or food processing so as to achieve better optimization characteristics; or a device to control an automobile engine to enhance fuel consumption under varying conditions.

27. The impact of the small computer will be felt both in the office and in macro planning, affecting mid-level clerical personnel as well as the character of top level activities.

28. Often, the microprocessor must be used with a sensor or transducer which supplies the input information. It has been said that the use of the microprocessors will be limited in developing countries by the cost of needed sensors. Even though there is some validity to this view in the short term, and, for certain applications in developing countries this may represent a limitation for some time to come, it misses two critical points. First, transducers fall rapidly in price (through new designs and higher volumes) once such new and wider applications become possible. This has already happened, for example, for heart rate sensors, and is likely to occur also for those sensors which have wide-spread application only in developing countries. Second, and relatedly, for the type of sensing needed (which is determined by the designed microprocessor function) very simple sensors can often be used to replace previously costly ones. The same type of impact has been felt in other related areas of componentry (e.g., switches, power supplies, analog to digital converters) where the microprocessor revolution has triggered the development of new generations of microprocessor-compatible components. And finally, of course, we should not expect to see microprocessors in wide-spread use in every area where they could be used; only in those that pay.

29. The very rapid introduction of new microelectronics technologies, the continuing fall in component prices, the steady trend towards ever smarter but easier to use devices are but stepping stones to the future. We need only recall that it has taken little more than a decade to go from the 1K (thousand byte) memory microprocessors to 64K and 256K versions.

30. For developing countries the implication is clear. Now is the time to build awareness and sensitivity to the opportunities, to begin the real learning that comes from actual involvement, to monitor developments, to develop and use the capacity to cope with imported products containing advanced microelectronics, and to begin self-sustainable development and control of those aspects of the technologies most appropriate to real needs and growing resources.

31. In the next sections some insight will be provided into the advantages and opportunities of the currently most important element of the microelectronics revolution, the microprocessors, as well as, the economic, skill, and social considerations involved, leading to the elaboration of a strategy for implementing this technology in developing countries.

3. MICROPROCESSOR OPPORTUNITIES FOR DEVELOPING COUNTRIES

32. Microprocessors have a number of inherent advantages over other types of electronics that can perform similar functions and these need to be recognized.

- Standard ("off-the-shelf", i.e. low cost) microcomputer hardware can be customized to perform virtually any desired function or control any process. This by-passes the need to be able to develop numerous and costly (high skill) custom designs made up of many connected individual discrete components or to pay the very high "up-front" costs of custom chips.

- Improved system reliability is another key advantage of microcomputer systems. The individual integrated circuits, such as the microprocessor, EPROM and RAM memory, and some peripheral chips are quite complex and sophisticated. Yet they have been proven to be as reliable or more reliable than some of the medium and large-scale integrated circuits used in standard logic design. In the vast majority of applications, the microcomputer system will have far fewer components than that required for standard logic and therefore, much higher reliability. The reduced number of components reduces power consumption and power supply size which also reduces power dissipation and heat generated. The end result of fewer components is a smaller physical package. Where previously several standard logic chassis were required, now a single microcomputer chassi can effectively replace them.

- The ability to encapsulate "the works" when electro-mechanical devices (e.g. a counter or a switch) are replaced with microprocessor-based units greatly reduces the likelihood of breakdown through dust, corrosion, heat, misuse, poor maintenance, etc., extremely common conditions in developing countries.

- Better serviceability and less maintenance when these are needed are additional advantages of microcomputers. Because of the reduced number of components and increased reliability, less maintenance is required. When a malfunction does occur, a software diagnostic programme can be used by the service technician to provide assistance in locating and isolating the fault to the board level and sometimes to the individual chip level. Depending upon the application, it may be possible to program an unattended system to automatically run self-tests. Some of the other software diagnostics may include the ability to test controls and switches, displays and indicator lights, etc.

- Another advantage is easier field upgrading or expansion due to relatively easy expansion of modularized hardware, and the flexibility to reprogramme the software. The software programme can be updated and new memories programmed without affecting an operating instrument.

- Because the capacity of most microprocessors generally far exceeds the demands put on them by a given application, once such a chip has been incorporated, it can be made to perform many more functions at very little increment in costs. This low cost function expandability gives enormous flexibility and opportunities for creative applications to the product or process developer (or up-grader). One of the potentially very useful add-on features for countries with shortages in skilled service personnel is the ability to incorporate the above mentioned self-diagnostics for the processor to check out the rest of an electronics system.

- Shorter and easier development cycles are another advantage. These are made possible by the use of the pre-engineered hardware and modular programming. Modular programming by reducing the overall task to only that needed for simple replaceable modules which are functional by themselves, makes it far easier to carry out, hence reducing the training requirements. When a complex product is required, the necessary modules may be inexpensively linked together by a relatively small amount of custom software.

- The reduction in hardware componentry needed also has the important effect of making it possible to have much smaller, even miniaturized products. This makes it possible to develop small (and often cheaper) units, well fitted to many small-scale operating and process situations.

- The "cleverness" and speed of the microprocessor allows for the compensation of major inadequacies in other systems, skills, conditions or materials. Thus, microprocessors can make it possible, through continuous compensatory adjustment, to use poor and variable grade fuels in engines; or to obtain better efficiencies from devices dependent on variable inputs such as wind and biogas; to consider the development of very low cost hearing aids by using signal modifications to cut down the noise and feedback inherent in low grade audio receivers and transducers; to permit low skilled technicians to perform very difficult processes (e.g., cardio or chemical purity analyses); and so on. These compensation-demanding conditions are common in the developing countries and in products and systems used by them. A significant consequence is the enormous potential for skill savings.

- Planning and optimization of large scale and complex systems (in transportation; linking farmers, storage and food processers; and even across the units of integrated large operations, etc.) is notoriously bad, even in developed countries. For the most part, data inadequacies, changing conditions and incomplete models have limited the payoff from systems analysis and operations research optimization approaches. Much more robust bottom-up models can be developed in which microcomputers (and even minicomputers) are used to optimize local operations subject to input/output information received from a linked network of such processor controlled units. This trend towards the use of a larger number of linked processors has become characteristic of leading edge Japanese factories. Developing country conditions make linked decentralized structures far preferable to highly integrated and centralized approaches, allowing for flexibility, modular and incremental change, etc. In conjunction with telecommunications capacities (another critical area for development), the micro and mini-computers will play a major role in making a decentralized optimization approach possible in national and even company planning.

- Finally, an aesthetic and psychological advantage lies in the ability to create more attractive and less forbidding products, which therefore seem more adoptable to ultimate users.

33. While the above-mentioned advantages portray the benefit side of the picture, they also point to the limitations. Microprocessors should not be considered where these "advantages" provide no real value to the producer or user. Nor should they be used where the economic and skill dimensions to be discussed below are not favourable. Even though there is an obvious advocacy dimension to this paper, it is not intended to imply that microprocessors should be used wherever they can be used. It therefore becomes a central aspect of any programme of training and sensitization to create the awareness of when (and when not) to use which type and how.

34. The microprocessor's capabilities and advantages have led product and process manufacturers to incorporate them at an accelerating rate. Consumer products, automobiles, machine tools, chemical processes, security devices and many other products now contain chips in large quantities. It will soon be impossible to buy an automobile or a T.V. set without one. Like it or not, developing countries will become users of such products and processes. The challenge is to become a good user.

35. This "induced" form of microprocessor technology demands several coping responses:

1. The personnel and systems in place to provide service (to automobiles, hospital equipment, consumer electronics, etc.) will need to be changed (through retraining or new structures, as appropriate). Experience in the developed countries has shown that the required transition is very difficult, but cannot be avoided. Older service people have shown themselves to be slow to adapt and it has been necessary to develop innovative training approaches to overcome this resistance. The use of video-based programmed instruction/training has been shown to be effective. Such a programme has been developed in the U.S. with Commerce Department support by Northwestern University and adopted by the Electronics Industry Association. Besides training, service systems that allow for diagnostics and module replacement in the field are needed.

   Microprocessor servicing is not more difficult. In fact it tends to be needed less often, and once understood and prepared for, it is usually easier. It is just that it is different, and therefore can be frightening to those unfamiliar with the technology, and who may for the first time find themselves dealing with a smart device (a computer).

2. Even relatively standard imported products and processes may allow the possibility of a substantial degree of tailoring to needs, given the flexibility inherent in the microprocessor, if the user is sufficiently knowledgeable about capabilities to ask for or add such modifications.

36. There is a second type of induced involvement for developing countries in the microprocessor revolution. This concerns the need to stay competitive and cost-effective in some of the products, processes and systems currently being produced in developing countries for both domestic and export markets, or likely to be in the future. Again there will be little choice if the incorporation of microprocessors becomes the standard in those particular applications. Without them, the combination of needed features, costs and performance would simply be unattainable in many cases. This would be as true for exports to other developing as to advanced country markets. In this case, the skill requirements would have to be of the product development and production varieties. The same situation would apply where there are joint ventures with foreign firms utilizing the microprocessor in their designs.

37. More significant in the long run for developing countries will be those "autonomous" applications developments that can enhance their development. These can include products and processes to increase effectiveness and efficiency in all sectors within the economy, and also to open up new export opportunities.

38. Providing a list of such applications presents a dilemma. The potential is almost unlimited, constrained only by experience to date and the knowledge and imagination of the developers and users. Appended to this paper is such an illustrative list. It is given in the recognition that the natural and proper skepticism of policy-makers demands such a "show me" list. The applications, described in the appendix, cover products, processes and systems that have already been developed or conceived that appear relevant for developing countries. They have been deliberately selected so as to cover a wide spectrum of applications, products and processes that can be used in one or other of the production, service or resource-providing sectors of the economy (such as manufacturing, chemicals, food processing, agriculture, transporation, communications, energy, health care delivery) as well as directly by consumers. A number of cautions must be expressed in considering such a list of illustrative applications:

1. Most important, and with primacy, it must be recognized that we are dealing with a set of technologies that approximate another industrial revolution in the potential of their impact. The applications that can be described today are likely to be as limited in concept as any that might have been described at the onset of previous technological revolutions. Even in developed countries, only the surface of the applications potential has been scratched so far. By the same token, just as it is now obvious that it is impossible to develop a manufacturing industry without certain metals and other materials, working and assembling and testing capabilities, so equally will it be vital in the future to have in place the information processing capabilities of this technological era.

2. The majority of existing applications have been developed, so far, in the North and it is likely that very different patterns of use will occur in the South, reflecting the different needs, opportunities and resources. But these will only appear in quantity when developing countries have built up a critical mass of effort and experience with microprocessors. For now, most applications will tend to be selected and tailored extensions and conversions from those that have appeared in those developed nations that have become good users of microprocessors. It should be noted that even in the North there is still great variation in microprocessor applications capabilities with the U.S. and Japan well ahead of the few leaders in Europe; and that those nations that are behind have become greatly concerned about the gap and are making strenuous efforts to close it. It is interesting to think that a vigourous effort in developing countries could actually result in the achievement of a position in the application of this technology ahead of some countries normally (or one might say previously) considerably developed.

3. The real expertize needed to describe applications should derive from user-based and not microelectronics technology-based expertize. The microelectronics expert's role is to sensitize the user-based product developer as to what can be done and then show how to do it electronically, once the application has been specified. Naturally, therefore, a list of applications examples produced from a microelectronics perspective will be potentially subject to critical user questioning. The danger is that one becomes diverted from a discussion of the essence of the technological opportunity to a critique of the particular application.

With these cautions in mind, the list of examples in the appendix has been prepared as an attempt to create a level of awareness of the type and variety of presently conceivable applications.

4. REQUIREMENTS FOR THE APPLICATION OF MICROPROCESSOR TECHNOLOGY IN DEVELOPING COUNTRIES

39. It is vital to have a realistic picture of the cost and investment parameters involved in the application of microprocessors.

40. The key elements of the cost structure involved in the development and production processes are the costs of electronic componentry (the hardware) and the subsequent assembly and testing costs; the costs of the programming to provide the needed software; and the cost of the development systems that allow the programming to be done. Finally, there are costs involved in maintenance and service. Some of these elements are quite volume sensitive.

1. Electronic materials (chips, memories, peripheral devices) can cost in total anywhere from $3 to $75 at high volume (over 7,000 - 10,000 units a year) up to from $20 to $200 or more (for volumes that go as low as 30-50 units per year), depending, of course, on the application. To these costs must be added non-electronics components (housing, knobs, etc.) plus any needed sensors. It is to be kept in mind that most developing country applications will probably make use of the small memory 4 byte and 8 byte microprocessors which are already very cheap rather than

the newer and still more expensive 16 or 32 byte versions (although even these become cheaper by the month).

A useful strategy for the small volume and the new user is to identify chips that have been produced for larger volume users and therefore available at very low cost. The great flexibility of the microprocessor (if properly selected) enables a different user to customize in ways that can make it very appropriate for his application. While this is not always possible, it frequently is. Here again, traditional ideas which assume that advanced components from developed countries will not be appropriate for developing ones proves to be invalid.

Finally, with respect to materials costs, going from an electromechanical or purely mechanical device, for example mechanical control devices and switches, to an equivalent electronic device will, frequently result in a materials cost saving; and the electronic device will usually also be more effective and capable of more functions.

2. Assembly costs, the main part of electronics manufacturing vary with the size and complexity of the application. But given the smaller number of components to be assembled, it will generally be cheaper to produce a microprocessor-based product than an equivalent alternative electronic device.

3. Software cost will also vary with programme complexity, but rules of thumb currently being used in the U.S. are $10,000 to $75,000 for a 4,000 word program, and up to 5 or 6 times that for large programmes in the 16,000 word range. It is likely that programming costs will be much lower in developing countries once the capacity exists. For example, several of the more advanced developing countries have shown themselves to be extremely competitive in software devel[illegible] and export programmes. Therefore, these costs cou[illegible] onsiderably reduced. Volume again is a factor h[illegible] e up-front programming costs must be spread over the [illegible] of products produced. Since, however, most developing country applications at this time would have smaller programming requirements (probably the $15-[illegible]0,000 range), the cost-per-unit at even modest volume levels would generally be acceptable.

The trends in software costs should also be noted. On the one hand, the percentage of software costs in total electronic systems development costs has been going up steadily from about 20% in 1955 to about 80% now. At the same time, programming for microprocessors is becoming continually easier and more efficient, especially for the smaller 8 byte units. The costs for a developing country to consider in software must include not only those of design, development, debugging, documentation, maintenance, etc., on specific projects, but also those of education. From a national planning perspective it is vital to understand that in microprocessor development the key skills needed, once the applications have been identified, are those for the creation of software. This could give developing countries a significant comparative advantage.

4. To carry out the development work it is necessary to invest in a microprocessor development system, together with certain supplementary devices. These can then be used for a wide variety of applications. The cost of such a "tool kit" will vary from $15,000 to $50,000.

5. Maintenance and service costs should be low in comparison with equivalent products and processes. There will be a special cost to retrain people and develop appropriate support infrastructures to cope with microprocessor based systems. If these are not provided for, however, the costs can be severe, since it is just not possible to "fix" units without the necessary knowledge.

41. The skill requirements for implementing microprocessors are of four main types. The first concerns the areas of need identification and applications specification. Where can microprocessor-based products be used most effectively, and with what performance, maintenance and necessary costs characteristics? This information can only come from those sensitized to the potential of the microprocessor but also expert in user needs and conditions. The second type of skill, and the predominant one needed for development, is software development, but linking into the production process. Since the products, process and systems that result have rather different characteristics from those familiar to users, it is necessary to develop the incentives for, promote adoption of, and assist the user to accept the new products and methods; and then to help the user to put the expanded capacity to its fullest and most cost effective use. Finally, as has been stated, it is necessary to develop the skills needed for service, maintenance and repair.

42. It follows from the above that one precondition for establishing this technology is the putting in place of a sensitizing and training process and the development of structures that can produce the needed combinations of skills. One possible approach to be considered would be the construction of user-microelectronics expert teams across a variety of applications areas. These teams should be linked in applications networks, by substantive area, regionally and globally. Such networks should also have available the assistance of more specialized teams of technology and applications experts. It will also be vital to develop the appropriate methodologies and structures necessary to be able to carry out the planned programmes. Involved here would be the creation of a data and dissemination system, including a library and a data base to maintain, collect and disseminate information relevant to various microprocessor applications in developing countries. The library should include information on the

latest technical developments, newly identified opportunities, locations of skills, etc., as well as basic information about microelectronics technology. A special emphasis would need to be placed on disseminating the technical and educational materials widely to faciliate diffusion.

5. STRATEGIES FOR IMPLEMENTATION

A. General Strategies

43. The strategies for implementing programmes to stimulate and facilitate the appropriate use of microprocessor-based products and processes developing countries and for building the infrastructure to maintain and improve them must necessarily reflect the wide variation in the likely applications. Nevertheless, certain general principles should be followed:

1. Strategies should begin by being essentially bottom or practice-up. As appropriate, the programmes should begin with well-identified microprocessor-candidate user needs and current practices, or with such products and processes that are already in use or being locally produced. The strategy should be one of first incorporating microprocessors into existing products, processes and applications where these can enhance use, improve quality or reliability, cut costs, etc. Only when the first incorporation and adaptation steps have been successfully launched, should attention then be turned to expanding the role of the microprocessor, significantly within existing applications and into new applications that require more radical changes in practice.

   This user and current practice "pull" strategy is much to be preferred over one that requires adopters to accept new, technology driven products and processes. The normal failure rate for "new" products and processes is so high that it would likely retard the implementation programme for reasons that had nothing to do with the value of the microprocessor. Even such a conservative approach must be preceded by a substantial research program to identify existing practice and application targets. Requiring a combination of user and practice-based as well as technology-based expertise, the programme should work through existing firms, agricultural research and extension stations, health centers, power generating and distribution authorities and other operating entities. Also, wherever possible, the approach should be to "build-out" from any institutions in developing countries that can be identified as having already begun to work on the application of microcessor and related microelectronic technologies. By the same token, use should be made wherever possible, of existing (or new) national and regional institutions in developing countries that have the potential to play significant planning, coordinating and educational roles in the programme. Such institutions may need to be strengthened in order to play these roles well.

   These recommendations imply that a first step should be to begin with research and study programmes to identify the most desirable application opportunity areas and the available resource base in various developing countries.

2. Relately, it is essential to develop methodologies for optimally promoting and disseminating the programme, structurally as well as operationally. A linked regional structure plus a "learning and improving by doing" strategy (that moves through a use, make, improve and innovate cycle) should be considered.

3. Every effort should be made to harness and exploit any appropriate sources of technology assistance from other developing countries (in a TCDC mode) as well as from developed nations.

   In the former case note must be taken of the growing level of relevant expertise that has begun to appear in a number of countries in Southeast and South Asia, the Middle East and Latin America. One firm offer to so assist developing countries on a TCDC basis has already been communicated to this author and others could unquestionably be obtained. Also, efforts should be made to promote the exchange of experience between developing nations through networking (personnel exchanges, visits, newsletters, information banks).

   In the developed country cases, it will be in the interest of both microelectronics supplier firms and of manufacturers of products and processes incorporating microprocessers to provide such assistance in order to expand their trade opportunities. Many of the firms interested in participating fall into the medium to small size categories in their countries, i.e., they are not necessarily the huge multinationals. Some of these small and medium-sized product manufacturers may also be excellent candidates for joint venture opportunities with appropriate in developing countries.

   Use should also be made of the skilled microprocessor applications engineering consultants to be found in various countries. It is to be emphasized that this type of needed expertize is very different from that needed for microprocessor design and research and therefore much less likely to be found, for example, in large electronics research establishments or in the electronics and physics departments of developed country universities. In contrast, the applied technology laboratories and research stations in both developed and developing countries that have missions to improve products, processes and systems that are used in industrial production, energy, transportation, health, agricultur, construction, etc., are likely to be excellent sources of information and technology. These sources are available in a number of countries and should be used.

4. The programme must build up a self-sustaining capacity through lagged but concurrent efforts utilizing:

   - Training . The objective should. for the most part. be on training the trainers, and will need to focus on microelectronics applications opportunities. This will include the design and use requirements, — e.g., how the microprocessor functions in different product systems, software development requirements, interfacing needs, tranducers, power sources, examples of applications and cost/benefit considerations; the types and characteristics of microelectronics available; maintenance and service; technology trends and future opportunities; methods and approaches for successfully introducing and diffusing applications (i.e., on how to train users). Training periods of 4 to 9 months (depending on prior experience) will be needed. Ideal candidates will be electrical or electronic engineers or others with some technical plus programming backgrounds.

- The build-up of experience and confidence among users as well as producers through selective model applications in each country. These model areas should be selected according to criteria such as the following: 1) Several different sectors (such as industrial, transportation, agricultural, food processing, health) should be involved. 2) The applications should illustrate the variety of types of involvements, such as:

  - Incorporation in applications that deal with a local need or problem (e.g., a food storage control application). The examples, which should be modest in scope, should be selected to take advantage of already existing and well functioning delivery systems.

  - Incorporation into products (including some modest product expansion) already being produced for domestic and/or export markets. The objective here is to build on and to strengthen an existing production base. This would be the ideal forum for trying out some joint ventures. The approach to be used with respect to promoting joint ventures should be to identify the potential partners in developing countries and in some of the newly industrializing and developed countries, and then in facilitating direct, two-way, firm-to-firm contacts. Processes already exist to promote such arrangements and several potential joint venture partners, as well as possible financing sources, have already begun to be identified.

  - Develop or strengthen the service capability for imported products that are beginning to contain microprocessors. Since this will have to be done anyway, the objective will be to "show the way."

  - Initiate research activities at selected centres of excellence that will focus on the development of new types of applications not likely to be found in the North but particularly relevant in developing countries. The objective here would be to insure the longer term integrity and independence of the efforts.

The above criteria can be illustrated in the following matrix.

	Sectors					
	Industry Areas				Health	Transportation
Type of Involvement	Metalworking	Wood	Agro	Food		
1. Problem Solving	e.g., quality improvements, material savings or spoilage reduction				new services	reduce breakdowns
2. Product Enhancement	e.g., Improved features Reduced costs			—	—	—
3. Servicing	Equipment maintenance	—	—	Controls	In hospital equipment	Autos
4. Research	New products and processes				New applications	

The models selected should cover some appropriate mix of cells; obviously not all. Also, the mix could be achieved on a regional basis, each country having some examples. The examples in the cells are meant to be illustrative only.

5. Finally, it is important to point out the criticalness of timing. Microelectronics is in a period of rapid development. Patterns are being established now that will have long term implications. It is essential that developing countries establish their stake in the industry early enough to avoid being locked into a condition of inappropriate dependency. Therefore, even though the strategy being recommended calls for an initial modest and gradual learning and capacity building phase, it will be vital for this to be followed up by an accelerating and large scale effort, in a second phase. Furthermore, it is important for efforts to begin quickly.

B. Specific Plans

Phase I. Introductory (12 months)

- Set up coordinating and planning structure
- Initiate an on-going research and study programme that will begin with a survey of needs, resources (skills, institutions, firms, etc.), opportunities and constraints (such as social-economic and institutional impediments). This information should become input for a series of workshops and conferences (probably regional) that would serve both to obtain national commitments and to select an appropriate mix and allocation of model pilot projects. It is recommended that even the larger and more developed countries limit themselves at first to no more than 5 or 6 projects and fewer for small nations.

It will be necessary to provide initial training and to develop methods for carrying out this needs assessment and resource surveying phases. The research effort would then shift to the longer term development aspect described above.

- Once the pilot applications areas have been established, training should begin on a limited scale to:

  - sensitize policy-makers at the government and institutional levels;

  - sensitize users, extension personnel, etc., to potential applications and approaches in the selected areas;

  - develop the capacity of those persons who will become the microprocessor application engineers on the initially selected pilot applications, and then the trainee of others;

  - begin to develop the capacity of researchers such as university faculty to work in this area.

The above training programmes should be carried out in developing countries and in the technology source countries.

- Develop methodologies.

- Initiate pilot programmes. This should be done in steps, beginning with one or two projects, gradually feeding in the others over phases I and II.

- Conduct a Phase I evaluation and hold conference(s) to review results.

2. <u>Phase II. Intensification of Capacity Building</u> (13 to 24 months)

- Expand training efforts, now using those trained in Phase I.

- Intensify project activities -- all pilot projects under-way.

- Launch expanded research efforts.

- Set up data and dissemination systems.

- Begin exchange efforts among countries and regions.

- Phase II evaluation.

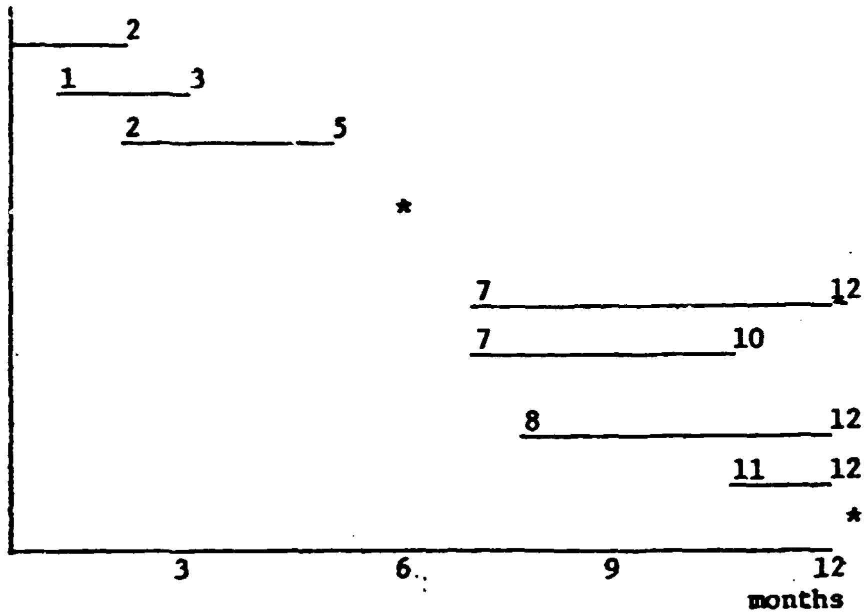
3. <u>Phase III. On-going</u> (3 to 5 years)

Expanded programmes of training, projects, research, joint ventures.

At this time only phases I and II are beirg proposed, and even these two phases could be adopted sequentially. A possible programme plan is shown below.

Phase I

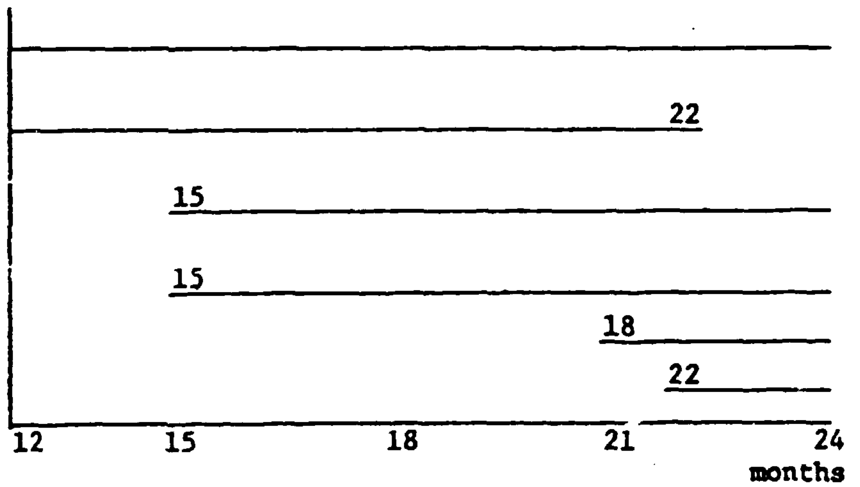
1. Set up structure
2. Initial training
3. Survey
4. Decision-making conferences
5. Plot programme training
6. Develop methodologies
7. Initial pilot programmes
8. Phase I evaluation
9. Conference



(Note: Items 5, 6 and 7 are highly interactive)

Phase II

10. Expand training
11. Intensification of projects
12. Launch expanded research
13. Data & dissemination systems
14. Exchange efforts
15. Evaluation



C. A Caution

44. Some final words of caution are called for. First, this programme cannot be successfully pursued in a half-hearted manner. Substantial capacity building is implied, and this will call for providing substantial training to some of the most talented and skilled of developing countries personnel. It is easy (and dangerous) in this field to become lulled into believing that a superficial technical capability is sufficient for embarking upon a programme. This issue relates to the second caution. The programme must be built on a self-sustaining and growth-inherent capability. Otherwise developing countries will find themselves once again locked into a condition of dependency as the technologies continue to advance. Finally, and again relatedly, it must be recognized that while a programme in this field requires building a relation with the technology source firms from the North, these will have to be on a carefully designed and monitored mutual-benefit basis. Any strategies will need to give explicit consideration to this question.

APPENDIX: DEVELOPING COUNTRY MICROPROCESSOR APPLICATIONS

Industrial Process Control

This is a very broad field, covering, among other functions, materials testing, quality control monitoring of parts and finished assembled goods, automation of manufacturing steps in a factory, and testing of assemblies and products. Appropriate applications of microcomputer technology allows one to be more cost competitive and increases product quality.

There are numerous examples of applications. Among the possible examples are:

1. It is necessary to monitor and correct the amount of carbon, nitrogen, sulphur and other elements in each batch of iron or steel produced, while it is molten. The equipment now available to precisely control the quality of steel produced in developed country foundries is expensive and difficult to operate. However, it is possible to develop an inexpensive, simpler microprocessor-based system using slightly less accurate techniques which would nevertheless fit the needs of countries with iron foundries.

2. In developing countries, circuit board rejection is a problem in electronics manufacturing, but currently available testing equipment is expensive and costly to maintain. The alternative has been large numbers of skilled technicians to monitor and repair the boards. Microprocessor-based functional testers at a third the cost of parametric testers have been developed and would be relevant in developing countries.

3. In any chemical or biochemical industrial process, the microprocessor can achieve finer and more continuous process control (as compared to processes requiring human monitoring and control) so allowing for local optimization at various stages and locations in the process. These can then be linked together to achieve much higher total process yields.

Energy

1. Solar, wind, water and waste-heat based systems. Microprocessor applications to this area include efficiency monitoring and weather monitoring so that backup energy needs can be estimated before they are actually needed. These and similar energy systems often used at the village level in developing countries lend themselves to many microprocessor applications.

   (a) For example, user-owned generating systems using wind, water, waste heat, etc., are usually only capable of generating power on a part-time or part-load basis and power from a central generating station must be frequently connected and disconnected and constantly monitored by skilled personnel. Microprocessor controls can provide voltage and phase syncronization with the central generating station to allow uninterrupted transistion between local and central power, partial load allotment to each system, and automatic pumping of power into the local network.

(b) Small village generating systems have no peak demand sharing connection with a power grid and therefore must either run a large spinning reserve to handle short-term peak loads, a wasteful, expensive method, or suffer frequent black-outs whenever an unexpected peak load is placed on the system. A microprocessor-based system can control loads at each location, distribute loads, and cut power to non-essential users on a priority basis.

(c) The generation of electrical energy requires the use of either internal or external combusion engines whose efficiency is less than 35 per cent; two-thirds of the energy is pumped into the atmosphere as waste heat. Microprocessor-based systems could recapture, control and distribute this energy for use.

(d) Windmills. Microprocessors can be used to control the angle of the blade in response to shifting wind directions to greatly increase efficiency.

2. Fossil fuels. Fuel consumption and efficiency are the two major areas of technological impact. Numerous microprocessor-based systems exist to monitor conditions and control the mix for efficient gasoline usage in automobiles; to allow use of lower grade fuels in automobiles, etc. Highly sophisticated microprocessor systems monitor and control pipelines and other distribution systems. Monitoring and control of motors to increase fuel efficiency is another important application of microprocessor technology.

3. Nuclear energy. Safety is the major issue with nuclear technology. Microprocessor technology can be applied to allow the use of "fail-safe" techniques and monitoring. This implies that less skilled personnel might be used and still maintain a good safety margin.

Transportation Systems and Products

General applications to this sector include monitoring of fuel efficiency and consumption, monitoring and control of railway systems, and monitoring of airport systems. Some specific examples follows:

1. Trains suffer inefficiencies and damage due to differences in acceleration and braking tractions of the various wheels. Microprocessor-controlled traction feedback for each axle can solve the problem.

2. Newly trained drivers are prone to causing accidents such as backing trucks into walls, taking tractors over cliffs, etc. Signalling devices can be developed to warn of such impending dangers.

3. Water transportation and fishing can be made less dangerous by providing boats with depth calculators which can determine the rate of change of depth.

Products that can be used in the agriculture, dairying and food processing sectors.

1. Microprocessors are used for sprinkler control in irrigation, to regulate the timing and flow rate of water and to control the wheels of movable systems so they water a programmed area evenly.

2. Milk collection, handling, pasteurization and storage require skilled personnel in order to produce high quality, safe milk with a low rate of spoilage. In developing countries, trained personnel are still in short supply. This problem can be circumvented by using microprocessors in many phases of a milk-processing or pasteurization system. All functions, including system cleaning and sanitizing, can be controlled by microprocessors. While this type of automatic handling has been available in the United States, it does not incorporate microprocessor technology and is unsuitable in its present form from developing countries.

3. Microprocessors also can be used in monitoring and control functions in the milking process. Among the technologies available are the following:

   (a) Stall sensors to control warm water to the udder to increase milk production.

   (b) Sensors to measure the amount and richness of milk, as the cow is being milked and also when milk is brought in for marketing.

4. Prevention of spoilage during food storage. Spoilage is an ever-present problem where grain and other foods are being transported, stored and processed, and the problem is exacerbated in tropical countries.

   Several examples of available microprocessor applications in this important area may be cited:

   (a) High moisture content in grains causes spoilage and can make processing difficult even if spoilage is not a factor. Using a microprocessor-controlled tester, the grain can be pretested for moisture by even an unskilled user. Grain testers now on the market are difficult to use, expensive and inaccurate because they do not take into account all of the variables involved.

   (b) When large quantities of grain are stored, they are shifted frequently from bin to bin to prevent heat buildup and rapid spoilage. The act of shifting causes abrasion of the grain which in turn may promote spoilage. The shifting operation is generally based either on the operator's "best guess" judgment, or on temperature readings taken from thermocouple cables in the grain which are often inaccurate. A microprocessor-based control can read out, store, compare with past readings and ambient change, and then automatically shift the grain. The advantages would be minimum grain abrasion and spoilage and minimum energy usage in shifting the grain from bin to bin.

(c) Cans used for food storage must be coated inside with a plastic or enamel glaze. The integrity of the coating must be checked before the container is filled in order to prevent spoilage. Automatic testers using microprocessors are being developed in the U.S. A simple, easy-to-use enamel rater, controlled by a microprocessor, is needed for use and possible manufacture in foreign countries.

5. Process and food quality monitoring and control. Already, such processes as pasteurization, canning, and cooking are benefitting from microprocessor technology. Better quality and more consistent yields are obtained. Such functions as temperature, timing, humidity and moisture content can be monitored and controlled relatively simply. This is likely to especially critical for certain bio-technology applications, such as in fermentation processes.

6. Testers can also be developed to determine the quality of products brought to market (milk has been mentioned; the moisture content of rice is another) and also to then calculate the rates that should be paid.

7. Control systems that can monitor critical water parameters in fish ponds can be used to increase yields.

Products that can help to improve the delivery of health and medical services.

Automation of many health and medical functions, already possible with today's microprocessor technology, allows for more efficient use of trained medical personnel and great cost savings. It can make sophisticated services available even in areas where there is a shortage of trained personnel. Among the areas where microprocessor-based automation relevant to developing countries is possible are the following:

1. Patient monitoring and testing. Blood pressure, respiration, temperature, pulse rate from a sensor in a fingertip probe; heart monitoring from a small device held to the chest; blood analyses; fetal monitors using ultrasonic sound.

2. Control of life-support and other equipment. Heart-lung machines, respirators and wheel chairs.

3. Automation of clinical laboratory equipment. Blood gas analysis, hematology parameters, blood chemistry, cardiac parameters. X-ray enhancement equipment to aid the reading of X-ray images.

4. Development of low-cost hearing aids.

Products to improve communications and education

This last area is one of enormous, but as yet largely unexploited potential in developing countries. The microprocessor makes possible the development of low cost information networks that can provide for interactive and random access communication systems that make possible vastly improved educational approaches, and a variety of other improved information-based networks. The advances in microelectronics have also made possible more efficient, more reliable and less expensive telecommunications equipment and systems, and easier to do and cheaper printing processes.