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9. ABSTRACT
One of the most difficult questions facing donor countries is to determine the types and levels of technology that are best suited to the overall development needs of a particular LDC. The answer must be derived from a careful analysis of the LDC's economic, political, social, cultural, and populational situation. This volume presents twelve papers delivered in a seminar series conducted at the University of Arizona between September and December, 1976. The papers present views of specialists in industrial, civil, nuclear, agricultural, and systems engineering, physical geography, and cultural anthropology. The papers are: The Role of Technology in Developing Countries--An Overview, by Robert L. Bulfin; Appropriate Technology in Food Production, by Kenneth K. Barnes; Dual Technological Systems in Water and Grain Storage, by Hans Guggenheim; Appropriate Technology in the Industrial Sector, by Ross W. Hammond; The Appropriateness of Appropriate Technology, or, Can the Carabao Happily Co-exist with the Gasoline Engine?, by Simon Ince; Some Criteria for Choices of Technology for Developing Countries, by Hugh H. Miller; Remote Sensing and Developing Countries: Potential and Problems in the Transfer of a Technology, by Leonard Berry; Controlled-Environment Agriculture and the Developing Countries, by Wayne L. Collins and Carl N. Hodges; An Argonne National Laboratory Venture in High Technology Transfer, by Norman Hilberry; On the Introduction of Modern Agricultural Technology in a Developing Country, by A. Wayne Wymore; Some Emerging Modes of Technology Exchange in the U.S. Foreign Assistance Program, by Henry Arnold; Some Retrospective Thoughts on Technology in Developing Countries, by Robert L. Bulfin.

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The Application of Technology in Developing Countries

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Seminar Series
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Editors:

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Office of Arid Lands Studies

THE UNIVERSITY OF ARIZONA
Office of Interdisciplinary Programs
Office of Arid Lands Studies

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EDITORS' NOTE

The chapters in this volume are based on papers delivered during a weekly seminar series at The University of Arizona between September and December, 1976. These seminar series were originally held under the auspices of the University's Natural Resources Program, an interdepartmental activity made possible by a 211(d) institutional grant to the University from the U.S. Agency for International Development; the seminars are now sponsored by the University's Office of Interdisciplinary Programs.

In some instances, the chapters appear almost as given, with minor editorial changes; in other instances, extensive revisions have been made by the authors and/or editors, in order to accommodate the material into a more readable format, as required by this volume. We have also changed the sequence of the original papers and have grouped the chapters into thematic areas. Two of these are entitled "low-level technology" and "high-level technology," although we wish to make it clear that there is no implication that these titles have meaning beyond normal usage.

The volume, like the original seminar series, represents the varying, and sometimes differing, views of specialists in such fields as industrial, civil, nuclear, agricultural, and systems engineering, physical geography, and cultural anthropology; these views also represent both The University of Arizona and other nationally-known institutions.

We wish to thank Ms. Moir Spicer for manuscript preparation, Ms. Mary Ann Stone for graphic design, and Dr. Edmund Weber for technical assistance.

Robert L. Bulfin
J. Richard Greenwell

FOREWORD

Arguments as to whether the terms "intermediate," "appropriate," "village," or other such adjectives should preface the word "technology" have been most expressive during the last few years, and, as is the case with many adjectives, they often connote one thing to the user and another to the listener. While most technologists have always applied a technology that they believed to be the appropriate one, their ignorance of certain physical/environmental parameters and local social structure and ideology have often led to failure when they have returned home and left their technology behind.

Although many developing countries object to the use of the term "intermediate" because it implies "second best," the fact remains that most of Western technology is designed to be operated by well-trained and experienced people. Maintenance and spare parts are major components of Western industry, and sophistication is often such that operation and maintenance requires special tools and test equipment; also, most Western technology requires a high energy input. We have geared most of our technology to the philosophy of inexpensive and unlimited energy, water, and other resources, and have included trained manpower to operate and maintain hardware. Without such a base, technology cannot be easily transferred.

To properly do a task in any environment, the technologist must adapt his experiences and technical knowledge to that of the particular problem which is at hand, and the human and physical resources for operation and maintenance must be derived from the local setting. As an engineer, I was taught the KISS system (Keep It Simple, Stupid), but I believe that many of us have lost sight of the fact that, usually, the simpler the technology, the greater the reliability and endurance. It often takes more engineering intellect to design a simple system than to simply "plug in" some sophistication, and I believe it will always take more engineering skill to design "appropriate technology" than to merely transfer it.

This volume is divided into two parts: those papers dealing with "low-level" technology, as presented by Messrs. Barnes, Guggenheim, Hammond, Ince, and Miller, and those dealing with "high-level" technology, as presented by Messrs. Berry, Collins and Hodges, Hilberry, and Wymore. We are also delighted to include a special paper by Henry Arnold, from the U.S. Agency for International Development, which addresses the spectrum of U.S. foreign technical assistance, particularly

as it is the Office of Science and Technology, which Mr. Arnold oversees, that is responsible for providing much of the technology expertise to developing countries, and, incidentally, which awarded a 211(d) institutional grant to The University of Arizona, making this seminar series and this publication possible.

Robert Bulfin, as chairman of the seminar series on which this volume is based, provides a comprehensive introductory paper, as well as a timely summarizing paper. It is not my intention to steal the thunder from Dr. Bulfin, so I will close my foreward with this one hope: that this publication will contribute, in its small way, to furthering our understanding of the problems involved in technology transfer to developing countries. It is our desire and intention, at The University of Arizona, to increase our competence in this area, as well as to increase the expertise of the U.S. development community as a whole, and that of developing country planners; it is they who are ultimately charged with managing the technologies their countries will incorporate into their cultures, with both the benefits and detriments.

Jack D. Johnson
Director
Office of Arid Lands Studies
The University of Arizona

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Overview

The Role of Technology in Developing Countries: An Overview

ROBERT L. BULFIN*

The potential of technology to aid the plight of people in developing countries has long been recognized. Modern agricultural techniques, such as fertilization and crop rotation, could increase output enough to overcome starvation. Improved sanitation and the eradication of pests could improve health. People could have enough time to get an education, which could be obtained by technological means such as television. Improved production methods could make consumer goods readily available to everyone. These were the rosy thoughts of the effect of technology transfer on developing countries. But before we explore this, let us take a look at technology, developing countries, and the recent history of development.

If one looks up the word "technology" in a dictionary, one might find: "technology - the science or study of the practical

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or industrial arts." However, when most people think of technology, they form a mental picture of computers, automobiles, or large hydroelectric generators. I refer to this component of technology as hardware. Hardware is certainly important, and much of the effort of engineers and scientists has been in designing and improving hardware. However, there is another component of technology which may well be more important than hardware, but has been grossly neglected; this I call software. Software is the invisible component of technology, and may be considered in two categories. The first is technical knowledge applied to a particular task, or what might be called specific knowledge. This type of software may express itself as the decision procedure used to determine when and what crops a farmer should plant, or the knowledge of a skilled maintenance mechanic. The other type of software is the technology of the people, and may be considered as technical know-how. This knowledge determines the level of technology that a people are able to assimilate.

Aside from the factual aspects of technology, there exists an emotional response evoked by the word technology. The recognition of pollution, ecological imbalance, worker alienation, and the indiscriminate exploitation of natural resources, as problems identified with technology, have led many people to have a negative connotation of the word. However, technology by itself is neither good nor bad; it can cause problems if misapplied. Robin Clarke has provided five typical responses to the dilemma caused by current technology, which deserve brief mention here. These responses are called the price response, the fix-it response, the away-with-it response, the radical-political response, and the alternative response. I will illustrate these responses with the problem of pollution. The proponents of the price response believe pollution is inevitable, but the benefits of technology far outweigh the effects of pollution. The fix-it responder would take care of pollution by adding more technology to alleviate the problem. The away-with-it responder believes that pollution is an inherant result of technology, and therefore as little technology as possible should be used. The radical-political responder would argue that pollution is a symptom of capitalism, and has nothing to do with technology. Finally, the proponents of the alternative response believes that non-polluting technologies can be developed.

Many of today's scientists and engineers would fall into the fix-it category. They feel that there is no need to make major changes in current technology, but that it may be necessary to modify it slightly in order to prevent undesirable side-effects. The alternative response, which on the surface seems identical to the fix-it response, is concerned with new, possibly radically different technology. For example, the fix-it responders might try to develop a pump which is more efficient in order to conserve fossil fuels, whereas the alternative response would be to develop

a pump that did not use fossil fuel at all, but a renewable power source such as solar energy.

The fix-it response may also lead to bad technology. When Buckminster Fuller was asked what the major problem of technology was, he related the following story: a manager of a steamship line was crossing the Atlantic on one of his company's ships. The ship hit an iceberg and sank. Just as the manager was going under for the third time, the top of the grand piano floated by. He quickly scrambled on the piano top, where several hours later a rescue party found him cold and wet, but still alive. When he returned to his office, he ordered all company ships to carry a grand piano top for each passenger. Several years later, a bright young engineer working for the same company was crossing the Atlantic, and the ship he was on also sank. He immediately crawled on his piano top, but the sea was very rough and it swept him off every time he got back on. Eventually, he was rescued. When he returned to the office, he immediately went to see the manager, and told him that he was grateful for the piano top. After all, it did save his life. But he thought he could come up with something better. The manager asked what that might be, and the engineer replied: "put handrails on the grand piano top." As you can see, the engineer was a fix-it responder.

Of course, Clarke's five responses are stereotypes, and no individual would fit into any category on every issue, but they do tend to point out the range of thought on problems associated with technology. Obviously, the most appealing response is the alternative response, but the development of alternative technologies is not trivial. The remainder of this seminar, and the following papers, will shed some light on this subject.

Now that we have discussed technology, let us focus upon development and developing countries. The U.S. Agency for International Development has a working list of least-developed countries. The criteria for being on the list is that the country be non-communist, and have a GNP per capita of less than $275. This definition leaves much to the imagination. Even among countries on this list there are large discrepancies in the state of development. This point was vividly emphasized when I was attending a development conference in the Philippines and the representative from Ecuador discussed his country's efforts to develop steel production facilities. The Ghanaian representative commented that they had to worry about agriculture so much that they could not even dream about steel production.

The term "developing" also presupposes the availability of resources to be utilized. These resources may take on many forms. They may be human resourcers or material resources, including natural resources. The amount and type of resources available tend

to aggravate the differences between the stages of development of different countries. Regardless of these differences, we all recognize a developing country when we see it.

A tougher question to consider is: what are the desired results of development? Everyone agrees that achieving a minimum standard of living is important. This would include adequate diet, housing, and clothing. Most people also agree that certain health standards and levels of education are desirable goals. After that, the accord breaks down. I will not dwell on appropriate goals at this time, but will return to them at the end of this paper.

We have been discussing both technology and developing countries. Let us now try to put them together.

As technology is the application of systematic knowledge to the solution of practical problems, so development is the application of technology to improving the conditions of life for a human society. But more technology does not automatically ensure improvement. Traditional development strategies consisted of importing the most sophisticated technologies of the developed countries in an attempt to increase GNP. But development strategies based on increases in GNP have failed to provide the progress once thought possible. After nearly three decades and over $120 billion spent in applying this strategy, two-thirds of the world's nations, containing 70% of the population, still have a GNP/capita of less than $500. This enormous export of technology has been accompanied by a remarkable lack of development, by growing unemployment in the cities, disruption in rural areas, and a widening gulf between the wealth of a few and the poverty of the rest. Let us now examine some of the reasons for this lack of success. I will do this through the use of examples.

The first example has to do with the scale of the technology utilized. A particular developing country had no manufacturing facilities for making electric batteries, and had to import them. Thus, it seemed logical to introduce a manufacturing facility for electric batteries, and so it was done. After completion, it was realized that this plant could produce the entire annual demand for batteries in only sixty days. There is also the case of the public-sector shoe factory which operated at 20% capacity because it had no means of reaching the small, private shoe retailers who handled 90% of the shoe trade.

The second example illustrates the fact that some technology may be too complex to be operated and/or maintained by local people. In this case, a $2 million date-processing plant was idle for over two years for lack of the technical expertise to repair the failed de-stoning unit. Of course, most of us have seen, read, or heard about tractors rusting in the fields where they stopped for want of fuel, parts, or the know-how to fix them.

Another example has to do with the use of imported raw materials rather than indigenous ones. This concerns a manufacturer of ceramic floor and wall tiles. The plant used imported presses but these could be repaired locally, and local clay was used as the raw material. Due to an increase in demand, a modern plant was built to replace it. This plant had high-speed automatic presses, continuous tunnel kilns, etc. This required very malleable clays, which were not available locally, and therefore had to be imported. The new equipment could not be repaired by the local mechanics, and therefore required the importation of repair parts and service.

Let us now consider an example of the energy requirements of modern technology. In the U.S., it requires ten calories of energy (excluding solar energy) to get one calorie of food to the consumer. Traditional agriculture requires one calorie of energy to produce fifteen calories of food. Recognizing the current pinch on fossil fuels, any attempt to transfer technologies that are energy-intensive are suspect.

It should now be apparent that the act of introducing technology alone does not produce development. In fact, even when there are no unpleasant effects resulting from the introduction of a new technology, the desired result of self-perpetuating progress may not be obtained. Witness the people of a fishing village who were starving because their nets broke easily and they could not catch enough fish. The government supplied the villagers with nylon nets, which enabled them to catch enough fish to have an adequate diet. However, this led to no further development, and the people were still dependent on the government to furnish them nets.

Another example points out the ecological damage caused by some technologies. When the Aswan Dam was built, it created swampy areas in which a particular type of snail thrived. This snail caused the outbreak of a disease of almost epidemic proportions. In addition, silt build-up in some places was so bad that it was more difficult to obtain water than before the dam was built.

Of course, socio-cultural aspects may cause technology to backfire also. An African mining company tried to use posters to encourage workers to follow certain safety precautions. A series of posters were used representing correct behavior, culminating with a smiling worker being paid. However, the poster showed the worker receiving his wages with one hand, and, in this particular culture, things are given with one hand and received with both hands! Thus, the workers perceived the last poster to be a worker making a donation, which obscured the "moral" of the series of posters.

The government of a developing country may inadvertently enact laws which are detrimental to development. In Ghana, about 60% of

the soap is produced by a large foreign manufacturing concern, with small manufacturers supplying additional soap. However, there is more demand than soap available, and since the government has fixed the price of soap, there is an active black market. The Technology Consultancy Centre, at the University of Science and Technology, Kumasi, developed a small soap manufacturing plant which was within the price range of most small entrepreneurs. But the cost of making the soap is high relative to the price, causing the profit margin to be so small that entrepreneurs do not enter the industry. The foreign soap maker survives because of volume and economies-of-scale. Large numbers of people must then go without soap, or pay exhorbitant black market prices. By removing the price control (or raising the price), the government could encourage small entrepreneurs to enter the industry, creating more jobs with little effect on the average price of a bar of soap.

The last example will deal with a "technologically-successful" development project. A country imported two plastic injection-molding machines costing about $100,000. Working three shifts with a total of forty workers, the plant turned out 1.5 million pairs of plastic shoes and sandals a year. These sandals were of good quality, and at a price of $2/pair were within the budget of many people. But 5,000 artisan shoemakers were put out of work. Likewise, suppliers of leather, hand tools, thread, tacks, glue, polish, eyelets, fabric lining, wooden lasts, and cartons had large declines in demand, since these materials were not required for plastic footwear. Further, all of these are indigenous materials while the material for plastic footwear had to be imported. The net result was a decline in both employment and real income for the country.

You may think that these examples were carefully chosen, and you would be right. But they are not atypical. If you look in the development literature, you will find many reports of similar experiences.

I also know that some of you are smugly thinking that you could not make mistakes like these. That was my first reaction too. However, I assure you that we can. The people doing these projects were not dumb. They are simply dealing with projects so complex that it is difficult to foresee all of the eventualities.

How does one avoid the pitfalls of the previous examples? One way is to learn from past mistakes. I have constructed a list of appropriate considerations for using technology in developing countries. This list is not intended to be all-inclusive, and there are elements on the list which would not apply in every case. The following are the key considerations:

1) labor - does it create jobs?
2) scale - is it incremental?
3) resources - does it use indigenous resources?

4) acceptance - are local people involved? is it culturally sound?
5) ecology - how will it affect the environment?
6) future - is it self-perpetuating? does it lead to new knowledge?
7) people - does it promote self-respect and independence?
8) cost - is it cost effective (including social costs and revenues)?

If you think about this list, you will see that the elements could be construed as goals. These goals may or may not apply, depending on the situation. The goals which do apply certainly have different weights.

Another facet of choice of goals concerns cultural disruption. All technology causes changes in the culture, but usually they are gradual enough to be easily assimilated. Now that we are transferring technology, the technology is changing rapidly enough to create potential cultural problems. It is time for social scientists to take a more active role, and keep the engineers from making too many drastic errors.

I also feel that the initial expectations for development were too high. We would not expect a person to run before he could walk, but this is what we are doing when you give a tractor to a man who has never used a bullock-drawn plow. Development does not have to take as long in the developing countries as it did in the now-developed countries, but it cannot happen overnight; it must be incremental. Developing technologies that can be assimilated and still compete with so-called modern technologies is extremely difficult. But it is not impossible.

My final conclusion concerns technology not in developing countries, but in developed countries, and, in particular, the United States. Our usage of the world's limited natural resources has been likened to the chain letter swindle. The beneficiaries of the swindle are the ones who got in on the ground floor (developed countries), who attempt to maintain the illusion that late joiners (developing countries) can also reach a point where dividends received are greater than the inputs of natural resources. Intuitively, there must be a limit, and this limit is being rapidly approached, particularly in the area of fossil fuels. Thus it may be necessary and desirable to utilize technology developed for the Third World in the U.S. As I mentioned earlier, U.S. agriculture requires ten calories of energy for every calorie of food consumed. Most of this energy is expended in preparation and transportation; by extensive use of family gardens, this energy might be saved. Therefore, let us conclude with Voltaire's words: "That's very well said, and may all be true, but let's cultivate our garden."

* * *

Discussion

Q. I spent a year working as a fishing development aide in Palana, a small island in the South Pacific. I think you'll find that when you talk to the people in a developing country they are not interested in windmills, methane digesters, and things like this. They are interested in cars, nuclear reactors, and clothes. For example, on the island where I was, in 1950, it took two days to get from the far end of the island to the bottom of the island in an outrigger canoe. Today, with a Johnson 150, you can get there in about 4 hours. You're not going to go back to outrigger canoes.

A. Two pages of my paper, which I pulled out this morning, try to address that problem, although I came to no conclusions. The real problem is that we can't tell people what their goals should be, particularly when we behave in the manner we do. However, I think that we should try to impress upon them the value of learning from our mistakes. You know the old platitude: "Money doesn't buy happiness." If I may quote Shaw: "The man with a toothache thinks all men with sound teeth are happy; the poor man makes the same mistake as the rich man." All we can do is try to tell people the way things are here, and I am not so sure things here are as great as some people think.

Q. There is one comment I would like to make about the sandal factory. If I remember your figure correctly, you said there were about 5,000 people put out of work by the factory, which made one and a half to two million sandals a year; thus, the people suffered. I can't believe your statement is quite right. In order for the factory to sell the sandals at $2.00 a pair they had to be competitive. What was the price before? Now let me assume two cases, one in which the original cost was marginally more; then, I think your statement was right. However, now assume that the people who had to wear the handmade sandals had to pay $3.00. Then, the whole population saved, on the average, $1.00 on a pair of sandals, which amounts to one and a half to two million dollars a year. The average people have that much more disposable money or, alternatively, the government could tax them higher and use these funds for social programs. You have to be really careful about your statement; you have to look at all sides. I think you have to look at other factors too. If you save two million dollars at the cost of putting 5,000 people out of work, you would still be ahead economically for you could put them on welfare or public work projects at $200 to $300 a month and still be ahead. I'm not arguing as to what you do socially, or psychologically, but you do have to look at dollars and cents also.

A. I said that it was "technologically successful." That brings up an interesting question: where does the wealth go? I think we have got to worry about that, and not just in a political way. When engineers introduce high technology, we have to bring into question things like economics, the social impact, etc.

Q. Everybody who buys such a pair of sandals and saves a dollar in the process will consider the enterprise as a success. Every extra dollar spending power they can obtain and use is important to them. Thus, you have to balance that against the economic losses incurred in the other fields, including what happens to the people who don't sell hand-made shoes anymore, and the shoemakers who stop making them.

A. In many cases, what you actually accomplish is a wasting of the productivity of workers in a local area, and you ultimately eliminate the demand for the product. If people don't have jobs, they can't afford to buy a product that you have built an industry to supply. In these terms, it is a failure. If you look at it narrowly, it's a success, but if you look at it from a wider perspective, it's a failure.

Low-Level Technology

Appropriate Technology in Food Production

KENNETH K. BARNES*

Identifying and applying appropriate technology in food production is a great and vital challenge throughout the world today. Even here in the U.S., many persons question the appropriateness of our technology, and some even question the appropriateness of producing food here in Arizona.

We all know, as we enter the fall semester of the academic year, that the appropriateness of any strategy is much easier to judge on Monday morning than on Saturday afternoon or evening.

When I was in Kenya in 1975, our party met a Stanford University geographer named Bruce Johnson, who was serving a two-year term at the University of Nairobi. We held some discussions, exchanging

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views in his office, and later met him at a social gathering. On the second meeting, he said to me: "You are the only agricultural engineer I ever met who did not recommend big tractors as the solution to all agricultural problems." He thus did affirm that it was my mode to give some consideration to appropriate technology. I do think, however, that he must have been rather limited in his experience with agricultural engineers.

Much has been written regarding the concept "appropriate technology" versus the concept "intermediate technology." Ademola Banjo reviewed the issue under the title: "Pros and Cons of Intermediate Technology." The discussion emphasizes that "intermediate" carries the connotation of "obsolete." Many persons object to the use of discards or hand-me-downs, and persons in developing countries may be particularly sensitive in this regard. On the other hand, everyone can agree on the appropriateness of appropriate technology. Appropriate technology, even if a simple technology, may well be a new technology derived or revived by research and development. Thus, time is not spent arguing the appropriateness of appropriate. The effort can be directed to identification and development of the appropriate.

Robert Bulfin opened this current seminar series with the topic: "The Role of Technology in Developing Countries: an Overview." Bulfin's overview was so thorough and detailed, that he really left little that needs to be said. My discussion thus is devoted to amplification and illustration of certain of his points. The points chosen for attention are not necessarily selected on the basis of relative importance, but rather on the basis of my interest and experience. As I look ahead through the planned topics for this series, it is apparent that many of the other speakers will be following the same pattern. Banjo's discussion of the "Pros and Cons of Intermediate Technology" suggests that appropriateness is based on production, manpower availability, market size, and other social and economic considerations. Bulfin listed labor, scale, resources, acceptance, culture, ecology, future, and people as considerations of concern in determining the appropriateness of technology. Some or all of these factors control the change or rate of change that a given group of people can and/or will accept.

Here in the U.S., for example, there are people who will not accept automobiles, trucks, or tractors. Some of these same people do, however, accept the internal combustion engine, and will use a hay baler with a mounted engine operating the baling mechanism while the total machine is pulled by horses. I do not understand that belief, but I do understand that, if I expect to sell these folks a hay baler, I had better accept their belief and adjust my baler, my proposed technology, to that belief.

Thus, if I want to sell an improved food production technology in a developing country, I must adjust my technology to their culture.

Let us remember that we do not have to go halfway around the world to confront this issue. Right here in Arizona, Stanley Throssell, writing about guayule as a possible crop for American Indian farmers, makes the point that innovations requiring vast technical knowledge which could threaten existing cultural foundations will not find ready acceptance by Indian communities.

The emphasis of my discussion of appropriate technology is the appropriateness of the technology to the local people. Without the people, there is no problem.

Let us examine, for example, the serious soil erosion problems of Lesotho. The soil has frequently been laid bare by the people and their animals in a desperate struggle for food and feed. During several years of less than normal rainfall, the struggle becomes particularly intense, the soil becomes particularly vulnerable, and when the rains come, the soil goes.

From the viewpoint of modern technology, the solution is simple. The erosion controlling practices are well known. With a suitable infusion of capital invested in earth moving and reinforced concrete, the problem can be solved. Then, if the local people are all just chased away, the solution will last forever. In fact, if the people are chased away before the technology is applied, the erosion problem will gradually correct itself and no technology is even needed. Furthermore, if the people are not there in the first place, no problem will ever arrive for no food is needed.

The solution to controlling the erosion so as to sustain a maximum potential long-term level of food production lies in adjusting the technology to the people and the people to the technology. The solution lies in linking the two, the technology and the people.

Remember that that is exactly how we in this country arrived at our technological level. I believe that peoples in developing parts of the world must also go through an evolutionary process as they adopt an increasingly sophisticated technology. The evolution can be accelerated by import of knowledge, but evolution it must be.

What does a Pokot woman in Northern Kenya understand of an aircraft? But then, what do the pilot and passengers of the plane understand of the Pokot woman's technology? I have a tremendous respect for her ability to survive in that environment. She knows something I do not. As I approach her food production problem, I hope that she is going to benefit from my experience, but I believe that I must also benefit from her experience. She and her people are there. They are alive. They are eating. I must first learn what they are doing and why; then, perhaps, I can make changes which will be both effective and accepted. They must be accepted to be effective.

In Lesotho in the 1930's, the British, who at that time held virtual dictatorial power, decided to solve the soil erosion problem. They put all of the sloping farm land into strip cropping. As I understand what was done, alternate strips of permanent sod and of row-crops were established. The alternate strips were about 18 feet wide and on the contours. Runoff from cultivated strips was to be caught by sod strips. Natural waterways were to be maintained in permanent sod.

Had I been involved at the time, I am sure I would have regarded it as appropriate technology. It was simple, it involved no great input of capital, and it involved no new kinds of tools. But from the vantage point of the Monday morning quarterback, it apparently was not appropriate. It did not work. Because of some combination of lack of local understanding of the practice, incompatibility with local custom, and pressure to produce more food, there was progressive intrusion on the sod strips and waterways until they virtually disappeared. Curiously, however, the contour habit remained.

Communal grazing was one of the factors not reckoned with. In Lesotho, the use of land is assigned to individuals for cropping. Grassland and cropped land after harvest are open to communal grazing. He who gets there first with the most animals get the most. Fencing is an almost unrecognized concept. Thus, grazing management is impossible.

But in Lesotho I received an interesting lesson in the art of learning the local practice and profiting from it. A group was promoting tree-planting in gulleys. Trees in general are not good gulley healers. They shade out soil-binding grass, and the course structure of tree roots does not help much. Tree plantings were very well received by local people, however, as they were a potential source of fuel and construction material. New planting of trees were respected. The village chiefs had tree-planted areas outlined with white rocks and the herd boys were instructed to keep cattle out of the tree plantings. The net result was a good stand of grass to heal the gulley. In that culture, tree plantings were excellent for gulley control. By the time the trees are harvested, the gulley is healed. If the harvested trees are replaced, and the new trees protected, the gulley will continue to be controlled.

In Kenya, on the other hand, fences are respected and land-use can be controlled. It is not uncommon to see a brush fence with bare ground on one side and heavy grass on the other. I had predicted that tree planting would be a poor practice for gulley control in Lesotho; my prediction was wrong because I failed to foresee how the people would respond to the technology. I must somehow predict what they will do in response to what I do, and what the ultimate results of my technology and its application will be. This prediction has come to be termed "technology assessment."

Marc Schieber, in discussing technology assessment, gives an example of the adverse consequences of a technology that defeated itself:

> Just a few years ago, one of the major aid agencies decided to support a project to improve the plight of the nomadic peoples of the Sahelian region. Since there was a general shortage of water in the region, and an underground water-table had been discovered, the agency decided to construct some 1,400 power-driven wells to tap the underground source and provide sufficient water for the inhabitants of the region. A most reasonable and pragmatic undertaking, so it would seem.
>
> However, as history now records, these well-intentioned efforts went awry. With the increased water supply, the nomadic herdsmen no longer migrated with their herds of livestock to other watering places and pasture land, but tended to remain at a well site. The size of the herds increased, because of the now abundant water supply, but the pasture around the well began to disappear. In order to feed their herds, the nomads began to cut down trees and shrubbery so that the cattle could eat the leaves. This left nothing to hold the topsoil in place, the desert winds did their work, and the Sahara began its most recent march. Soon the herds and their keepers (and the keepers' families) were faced with starvation. We know the rest.

It is easy to say: "technology assessment should be done." It is easy to say: "predict the consequences of an introduced technology." What is really being said is: "predict the reaction of the people of a culture we do not understand to a technology they do not understand." I suspect that it is not a job for amateurs to attempt to handle as a sideline to professional competencies in agriculture, engineering, or natural sciences.

Introduction of an agricultural mechanization technology may require a radical change in cropping practices. The involved technology assessment may be quite simple and straightforward, but the assessment must nevertheless be made.

Intercropping with two or more crops in the same rows at the same time is a common practice in developing countries. Corn, beans, and cotton, planted together, are regarded as having advantages over single plantings of each. Millet and pigeon peas are also often found together, and there are other examples.

U.S.-style mechanization removes the opportunity for intercropping. But before introducing a mechanized technology which requires abandonment of intercropping, it would be well to understand the why of the

cropping practice, and the appropriateness of a technology which mandates a change in the cropping practice.

Mere knowledge of a technology does not insure its adoption. Head-carriage of bundles is common in the world. In the U.S., the wheel is nearly universally used for light drayage jobs, and certainly the technology of the wheel is well known to many women around the world, yet they do not find the wheel to be appropriate. Does the lack of appropriateness arise from factors of economics, culture, or just plain convenience?

Close proximity to modern technology often occurs with minimum influence on the lives of many people. The herd boy in Lesotho living in a village adjacent to a well-graded road, where he daily is passed by a Mercedes-Benz, lives a life little different from that of his great-great-great-grandfather 100 years ago. The only difference I perceive is his garment, a tattered remnant of blanket which made its way out from some city, in place of his forefather's animal skin. This replacement was necessary because population pressure, the result of the adoption of one of our new technologies, modern medicine, has resulted in the disappearance of most large wild mammals from Lesotho.

A major problem in applying conservation technology is that, as the technology is applied toward a predicted and proven long-term gain in food production, there often must be a short-term loss in production. It is unreasonable to expect a hungry person to decrease food production today on the promise of more tomorrow. Today has to take precedence over tomorrow at the precipice of life. I do not here seek to address that problem, but it must be considered in selection of appropriate technology.

In such a context, the adoption and enforcement of conservation technology presents an overwhelming problem. In Kenya, there is a slope ordinance. The government has established a line on mountainous terrain, above which there shall be no farming because of the obvious folly of opening steep land to erosion. Yet many fields are cleared and farmed above that line. An airport interview with a district agricultural officer revealed the stark,cold facts of life away from our air-conditioned, ivy-covered halls. Our questions and his answers went like this:

Q. Flying in we noticed fields that seemed to be well above the maximum allowed farming slope. Were they in your district?

A. Yes, that's true. In response to population pressures, people are being forced further and further up the slope.

Q. Isn't this in violation of the law?

A. Yes.

Q. Who is responsible for enforcement of the slope law in this district?

A. I am.

Q. What do you do?

A. I go out and tell them they're not supposed to be there.

Q. What happens then?

A. They chase me away with spears!

I will never forget that conversation. To me, it summarizes the challenge of appropriate technology. Appropriate technology has got to be developed, adapted, tested, and demonstrated in the local environment, and that environment includes not only the physical but the social, economic, intellectual, and cultural. When you stop and think about it, that is as true in Tucson as it is in Timbuktu.

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Dual Technological Systems in Water and Grain Storage

HANS GUGGENHEIM*

For the last few years, I have been working on the development of appropriate technology for water and grain storage systems among the Dogon people in the Sahel, in the Republic of Mali. Yet, in spite of a conviction that we must conduct action-oriented programs, I felt ambivalent about intervening in the lives of the people and their environment. Never sure whether I play the role of huckster or helper when I introduce a project, I continue to be concerned about the problems caused by outside intervention.

I would like to discuss three old problems:

1. the rationale for intervention as aid;
2. the limits of absorption of western technology by a traditional socio-technological system;
3. the price of progress.

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These are not new questions, but they should be raised whenever we confront a new historical situation. These questions focus on the means and ends of actions, and answers to them are important if we wish to move beyond an incremental decision-making process to formulate policy and to make long-range development plans. For the governments of the developing countries, for the international assistance agencies, and for private donor organizations, these are fundamental concerns.

The idea of foreign aid may well have its origin in the Christian concept of charity as it was developed during the Counter Reformation in the 16th Century.

This concept held that the person who gives is interchangeable with the person who receives, and that giving was the way to approach Christ.

Two paintings of the time illustrate the notion: the first is a painting by El Greco, in which a Saint on horseback hands his cloak to a beggar. Both Saint and beggar have the same features. The second is by Velasquez, in which the victor at the famous battle of Breda bows deeply to the vanquished defender, who surrenders to him the keys of the city.

The paintings illustrate two different aspects of aid: the first is economic, the second political. Aid, even if it does not appear to be (as in the distribution of medicine), is economic in that it intervenes in the allocation of scarce resources. Aid relations are political in that they define a power relationship in which one side is the stronger, and the other the weaker. In the modern world, aid plays a part in the competition for power when it is linked with ideology, with the exercise of authority where it is linked to technology, and with the acquisition of prestige where it carries a hidden message, such as the grain sacs worn as sweatshirts that proclaim, "le grain Nixon," or "le grain Pompidou."

Outside intervention in a system during disaster periods such as droughts, floods, or war, often take the form of first aid (grain shipments, and blankets) and, although these forms of aid range from the ineffective to making the difference of life and death for large numbers of people, their long-term effect is small, and they are least likely to change the political or economic relations of a society.

Aid programs intervene in a society through the introduction of new technologies and exert a profound influence on political and economic relations. Technology, as I should like to define it here, is the means by which people transform energy to attain specific ends. Aid programs can come about because outsiders see a real or perceived failure of a socio-technological system, weakened by a catastrophe such as a drought, a change in the price of its produce on the world market, or a change in government. As a result, regular society finds itself in a state lacking in equilibrium. Such a society may not be capable of generating the necessary energy to reestablish this equilibrium of its own accord by its own traditional technology. Aid programs attempt to do so.

The philosophy of progress is that man can change his environment, his quality of life, and his future by virtue of his own will and effort. This idea emerged historically in opposition to the belief in providence and an immutable destiny. It has its roots in the scientific revolution of the 17th Century, the belief in knowledge of the 18th Century, and the faith in technology of the 19th Century. The French and American Revolutions provided a populist philosophy, and capitalism furnished the economic rationalizations. American history was read until the second half of the 20th Century as a triumphant confirmation of the faith in progress. Indeed, progress seemed a one-way street, and as predictable as the next green light.

In the 1950s and 1960s, Third World elites reinterpreted this Western ideology in terms of Marxism, Islam, traditional cultural values, and nationalistic feelings, but held to its basic assumptions. In the new nations, belief in progress thus became the core of the ideology of progress, and the inspiration for development. Aid for development became politically possible because it was shared by both donors and recipients.

But in the post-industrial era, the belief in progress eroded in the western world, just as millions of dollars were being spent on foreign aid to developing countries. Scientific inquiry, believed to have been a fundamental virtue, came to be questioned as unresponsive to human needs; the accumulation of knowledge, once enshrined in books and venerated, moved into computers and became suspect. Technology itself, once the solution to all problems, was accused of being the arch-enemy of the environment, and a threat to the remaining resources of the world; and irrespective of political systems, the distribution of wealth and power in the world was seen to continue to polarize the rich and the poor at an increasing pace.

If the historical components of the idea of progress are thus challenged, can the concept survive? If there is progress in the sense of a uni-directional advance towards some given goal, is the price too high in terms of unanticipated consequences? Development programs are a means of accelerating change and of moving towards specific goals, which are usually defended in the name of progress. Yet, there have been disturbing and unanticipated consequences.

If we wish to restore the generative powers of the original ideas of progress and aid, we must reexamine our programs from a fresh perspective. Such an examination must take us beyond an evaluation of the size of capital transfers, repayment of credits, the attainment of output targets, and of agricultural or economic efficiency. Aid for development has become a moral problem that needs to be thought about holistically in the context of our own national values and aspirations as they emerge today.

While aid is sought by the developing nations, the impression is often given that, to provide such aid, is a privilege for the donor that can be revoked any time and at will. The large degree to which development programs fail to fulfill their promise, or to which such programs leave economic and technical control in foreign hands, often justifies developing country suspicions. On the other hand, development packages redistribute

power and wealth unevenly in the receiving nations and create new inequities. What appears as aid to the general progress of a nation, may, in fact, work against the welfare of a given local population. Development programs, therefore, may succeed with benefits for the few at the expense of the many. The political and economic payoff is carefully weighed by the donor in terms of his self-interest. For the U.S., the problem is often that conditions attached to aid programs are perceived as interference in the affairs of an independent nation, and as attempts to gain economic or political control by means of dubious gifts. Yet, to give aid without insisting on some controls can place the U.S. in a position of helping to exploit a population by means of the very 'progess' that it introduces.

I should like to summarize the discussion up to this point in a heuristic paradigm:

	AID RECIPIENT	AID PROVIDER
Ideology	Belief in progress, but not necessarily for all	Belief in progress, tinged with doubts
Practice	Acceptance of aid, but fearful that it is a means of control	Belief in aid as good, or, in contemporary language, as self-interested altruism
Outcome	Inequities in the distribution of benefits: power and wealth	Political advantages and new alliances

I will illustrate these observations with materials collected in Mali, where I have been working since 1974.

I started to work in Mali in response to the Sahelian drought, and I concentrated originally on the construction of water harvesting systems on the Dogon plateau. My first water-storage system was based on the model of a traditional Dogon granary, and so I found myself eventually working on problems of grain storage as well. The idea underlying these constructions was that of an "invisible technology," by which I mean the use of high technology in such a way that it would not destroy the visual and aesthetic relationship of a culture to its environment.

The Dogon began to move into the Bandiagara Plateau, where they now live, sometime between the 13th and the 16th Centuries. The area, now the 5th Region of Mali, consists of a huge flat plain that extends into Upper Volta, of long drawn-out cliffs of about 500 kilometers in range and about 300 meters in height, and of a plateau that declines gradually towards the Niger River. When the Dogon arrived, they were a warring tribe, proud of their horses and military prowess. They found an indigenous population, the so-called Tellem. These people were hunters, but also cultivated the fonio grain. This grain was cultivated without the need of iron tools, since fonio requires no labor. The Dogon, however, introduced a more powerful subsistence crop of millet, together with the art of iron-working.

This historical change of diet is documented both in myth and present consumption habits. The fonio grain is associated with the creation of the Universe; millet is associated with the coming of technology. The Dogon perceived enormous energy concentrated inside a single grain. They believed the fonio grain to have been the heaviest and smallest element in the Universe, which concentrated within itself enough energy to have caused the creation of the Universe, as it exploded in a spiraling arc. Associated with the energy of grain, they see water and fire. The first is life-giving; the second linked to death, as well as to human and artistic creativity. The first, water, is the energy of nature. The second, fire, is seen as the energy of culture. The seven kinds of millet were brought down to Earth by the heavenly water spirit called Nommo. On the occasion of his descent, he stood on a granary, and so once again the concept of technology, energy, and energy-storage are associated.

The free environment, the plain, the cliffs, and the plateau have offered different opportunities to the Dogon farmers, but have always presented the same problem: lack of water. The soil of the plains is composed of poor sandstone rocks, which permit only a few wells and hamper water research. On the cliffs, water can sometimes be found in small gorges, where runoff accumulates, but the inhabitants of isolated villages sometimes have to walk for as long as three hours in order to find drinking water. The region is part of the Sahel, and its annual precipitation is characterized by extreme variation, ranging from 300 to 600 mm. The Sahelian farmers distinguish these three important seasons: the rainy period, which can begin as early as June and last until September or October; the cool season, that goes from October to February; and the dry season, which covers the rest of the year, except for January showers. The contrast between these seasons is dramatic. A dry and parched land of sand and rock is transformed into a green paradise with rivers and lakes during the summer months, but then reverts to its desolate condition. The uncertainty created by the oscillation between years of drought and rain, as well as for the insecurity of rainfall in a given year, makes planning for the future a necessity. For example, 1976 was a year of relatively high rainfall, but most of the Dogon region experienced a lack of rain during late August, and rain dances asking the rain gods for help were held throughout the area. This mini-drought came at a crucial period in the development of millet, when the grain was in flower. Irrespective of the size of the plant or the length of time it takes for millet

to mature, the period between the beginning of flowering and the maturation of the head is always 31 days. Lack of water during this period can effectively destroy a crop, no matter how much it rains before or after. But in 1976, difficulties for the farmer did not end with the dry spell. In October, during the harvest, there were unusual late rains and heavy hailstorms. The latter smashed the millet to the ground. What had promised to be a good harvest turned into a near disaster.

The uncertainty of rain has helped shape the farming practices of the Dogon, and has become the basis for his emphasis on storage as a reduction of risk. It has also provided the basic underlying thoughts of his philosophy and art. For the Dogon, the Universe is engaged in a never-ending struggle between the forces of rain and life, personified by the normal, and the forces of drought and death, represented by the rebel spirit, the fox. All elements of nature, society, and language, are classified as belonging to one or to the other. Such pairs include, for example, light and dark, male and female, reason and intuition, paternal family and maternal family, right and left, sheep and goat, etc. Millet, for example, has to be sorted out prior to sowing because it is male and grows wild among the rest. The good millet, in contrast, is considered female. Water is classified as good water (the water of rain), belonging to the normal, and as black water, evil water, that brings sickness and disease and rests in puddles in the rocks, which belong to the fox.

For the Dogon farmer, then, security in a world of conflicting forces involves the reduction of risk. One form of this reduction is the emphasis on storage. Storage of grain and storage of water. At the same time, Dogon culture is fascinated with the unknown, with change, with agriculture, and with technology. "We will try anything," a Dogon chief once told me. "Bring us new seeds or a new tool, or a new solution to a problem, and we will try it." The Dogon regard outside help with appreciative interest, but with caution. This caution is based on the careful calculation of risks, and not on an inability to understand the new technology, or to weigh the advantages and disadvantages of the program to their own needs.

I had visited the Dogon some years before, but during the Sahel drought I decided to go back and see whether I could help them harvest water. I recalled the history of the Dogon granary which had been brought down by the "water spirit," and I wondered whether the Dogon would accept the idea that we could make use of the traditional granaries and convert them, or build new ones, to serve as cisterns for water storage.

I returned to the village of Sanga in January of 1974 to propose my idea. I was concerned not only with the idea of providing water for the Dogon, but with doing it in such a way that the environment would not be harmed. I was concerned about disturbing the aesthetic balance that the Dogon had developed between their architecture and the rocky cliffs, an aesthetic relationship that had achieved a magnificent balance between the works of man and nature. At the same time, it seemed to me, the Dogon would want to test the innovation, not only for its practical use, but to evaluate its role in the equilibrium of the Universe. For the Dogon, there

are social risks to accepting new technology. One factor is the jeolousy of others, should one succeed, or have more. There may even be the threat of witchcraft, or at least of social sanctions. Fear of jeolousy is so strong that women will bring in their harvest at night, so that their neighbors will not see them. The Dogon farmer is reluctant to disturb the order of society, and cannot even accept the innovation that would benefit him unless the Chief has first done so.

The same principle holds true within the family. The house and the fields are commonly held and controlled by the elder brother. It is the elder brother who must decide whether anyone can enter into a new venture that would impinge on the rights of the family, because it is the elder brother who has the ultimate responsibility for their welfare. When I suggested that an ordinary farmer might want to build the water storage granary at his house, he was unable to accept because the Chief has to do it first. An old farmer, when questioned whether he would like to work his fields with fertilizer, and plow the way the pilot farmer had done in an adjacent field, refused to do so on the grounds that his elder brother would have to give him permission.

In order to introduce the idea to the Dogon, I took a construction model with me, made by my students at MIT, and discussed it at great length with the Chief, the village elders, and other notables. It was agreed that we would go ahead, and construction began that same month in the compound of the Chief.

The water granary was built of local clay, just like an ordinary granary, but it had to be made waterproof and to be reinforced in order to withstand the water pressure from the inside. We used ferro-cement, a lining of chicken wire covered with a very thin coat of cement, in which the mixed proportions are three-to-one. In order to keep the water cool, a traditional thatched-grass roof was placed on top of the structure. The building blended with the traditional appearance of Dogon architecture, but, at the same time, it introduced an invisible technology that permitted the family to store 12,000 liters of water for the dry season. To get the water into the granary, we used the basic characteristics of traditional Dogon architecture. Some of the house roofs were flat and terraced and equipped with water spouts, through which the water was passed into the narrow streets during the heavy rainy season. But by placing the water granary adjacent to the house, we were able to channel such water from the house roof into the granary instead. Water was channelled through an opening in the roof of the granary, which was covered by a wooden door carved in the traditional Dogon style. The door depicts the family ancestors and the symbols of water, and recalls the role of the spirit Nommo in bringing water to the Dogon. A side benefit of this door has been a revival of the carving of such doors that used to adorn traditional granaries throughout the region.

While I was working on the water granary, a delegation arrived from another village, named Youga-na, located about 16 kilometers from Sanga, and asked me to come and see whether we could help. The work done in Sanga

involved essentially a single mason. The work at Youga-na, however, began to be a venture of a very different kind. It is here that I began to develop what I like to call "share technology," a technology in which the very ideas that go into making it, as well as the work involved, was shared by the population. I have moved my thinking from the idea of water storage systems from individual families to larger systems for villages, and from the concept of an invisible technology, to the idea of a share-technology. At one time, Youga-na had over 500 inhabitants, but many of its young people have left because of the lack of water. There are three wells: one of cement provided by the government, and two dug by the villagers. But all three are dry. Thus, the women of Youga-na are forced to walk three hours each day in search of water for their families and their animals, from either a place high up on the falaise, or from a very great distance along the plain. Today, one finds many of the houses in the village abandoned. The people of Youga-na do not want to leave their homes, and those who have been forced to abandon their village want to return.

When I arrived in Youga-na, it became clear for architectural, technical, and cultural reasons that the construction of water-granaries would be inefficient in Youga-na. Thus, together with the Chief and the elders of the village, we decided on another solution.

Close to the village was an immense rock-shelter that received the run-off from the falaise during the rains; the water did not stay inside it, but ran through it like a torrent. In order to convert the rock-shelter into a cistern, we would have to remove the boulders, waterproof the interior, and close its openings. It seemed like an impossible task. We decided to try. If we succeeded, we would be able to store a vast quantity of water and, at the same time, be sure of a very low-rate of evaporation due to the cool interior of the cave.

The rock-shelter emerged from the falaise and consisted of a boulder that was thirty-five feet high, which overhung a deep basin. It covered a thirty-five foot diameter area, which slanted downwards from its back wall, where the water entered. The opening at its base was about nine feet, six inches. Slanting upwards, the opening continued for another twenty-three feet, and then angled to continue for another eight feet. At that point, the opening was about six feet high, and was used as an entrance by women who went there after a heavy rainfall to catch some of the water that continued to pour in from the mountains after the rain had ceased. The back wall measured about thirty-five feet, and then slanted off towards the front, forming a kind of triangle.

The rock-shelter was thus open at three sides, an opening that varied from a few inches to three feet at the base, and to six to eight feet at the entrance. The inside surface was formed by a large porous rock that extended outwards from the back wall in irregular terraces, and dropped off abruptly towards the center forming a deep break. At the very bottom, the ground formed a basin that dipped below the ground-level outside.

The inside of the cave was filled with boulders weighing from one to two tons each. Many of these were perched perilously on top of each other

and were too large to be moved through the openings. The job of removing these stones required modern equipment costing thousands of dollars, or the skills of a megalithic society. We opted for the latter and succeeded in completing the job of creating a beautiful space that resembled the inside of a Moore sculpture.

After our return from the Dogon region, we went to Nara together with a Malian engineer from the Service Hydraulique, M. Samba Ba. While there, we were visited by the director of the Service Hydraulique, M. Lamin Keita, as well as by a young French engineer, Mark Frager. On our return from Nara to Bamako, it was decided that Mark should work with us in Youga-na and that we should be accompanied bv Abdoulaye Kante, a Malian technician who had experience in working on dams. The expedition now consisted of Ken Strzepek, an engineering student from MIT, and two members of the Service Hydraulique. We also attracted some additional help: a French doctoral candidate in ethnography, Jaqueline Michalet, who wanted to come and help, and M. Alpha Ousmane Ouolouguem, the representative of the Dogon government.

We now had an excellent working party and needed only to get ourselves and our materials to Youga-na. We had hardly started to work when the rains came with surprising suddennesss and provided a shock for all of us. We had worried that the run-off from the falaise might not be large enough to fill the cave, expecting the waters to enter at the level of the entrance in a kind of tranquil mountain stream. What happened was quite different. About 15 minutes after the torrential rain had started, waterfalls began to form along the falaise, but no water entered the cave. Suddenly, with a roar-like thunder, water crashed through an invisible opening among the rocks at the back of the cave and cascaded through the interior, forming a furious stream. When the rain stopped, the water had passed through, and the cave became dry once again. We were stunned by the force and quantity of the water, and continued our work with a new awareness of the forces we were facing.

On the third day, my friend Abodjo, the mason who had built the granary at Sanga, arrived; he was knowledgeable in the use of ferro-cement. We then built a retaining wall along the open sides of the cave, using the traditional Youga-na house building method of fitting rocks on top of each other, starting with the largest at the base and ending up with smaller ones near the top. On the inside of the cave, chicken-wire was stretched against the walls and laced through the openings of the rocks to the outside. This reinforced the cement with metal forming ferro-cement, a technique developed in the 19th Century in France for boat-building, and now revived because of its simple and effective method for creating strong waterproof shells.

While we were working inside the cave, the women of the village fetched clay, sand, and water. The interior surface had to be evened out by rock fill-in, over which the clay was placed to provide a water-impermeable base. Then cement had to be mixed to cover the walls and the interior.

However, just as the first coat of cement had been placed on the walls, the rain struck again.

It was 3:00 p.m. when the rain started, and 3:17 p.m. when the water came crashing into the cave. Seven minutes later, the water had risen almost to the level of the entrance, filling the cave with close to 300,000 liters of water. Then the still soft, fresh cement began to dissolve, and water poured out of small holes. The walls, however, did not break under the pressure, and not a rock moved.

We then placed a layer of cement between the first rock wall and a second that was added from the outside. Cement was also brushed on top of the clay base. We wanted to make certain that an onrushing rain would not destroy our work and trap us inside, so we left a small opening at the base. When we closed it on the evening of the tenth day, we hoped for some curing time, but rain came at 1:00 a.m. and once again filled the cave at great speed. The walls held tight this time, but we lost some water through the recently closed opening. (This no longer posed a problem, and we arranged with M. Abdoulaye Kante to return towards the end of the rainy season to add the third and final layer of cement. This layer had to be mixed with cycalide, a water-proofing compound used in dam constructions and some time had to elapse before this could be done.)

We had been successful, although small leaks continued to give trouble. The huge rock-overhang resting on the wall looked like a gigantic sculpture. The young people of Youga-na then decided to hold a dance to celebrate their achievement. Thirty-two men and twenty-seven women who had helped in the construction celebrated with a new song: "We will no longer have to do without water, we will no longer have to walk so far to search for water--Life will be good to us, we will stay in our village." This was indeed a tribute to our work.

Let us now turn to the question of millet production and grain storage systems in Mali.

During the 1960s there was very limited U.S. aid to Mali, but following a military coup in 1968 there came a more pragmatic attitude; however, it was not until 1974,and the realization of the magnitude of the disaster caused by the Sahelian drought, that American aid began to pour into the country. Beginning in August 1974, large quantities of sorghum and maize were flown into Mali, which prevented a major catastrophe. This made-up 45 percent of all the grain shipped by donor countries. However, due to the immense difficulties of distribution, large quantities of grain were left stranded in the capital, Bamako, and in the regional centers. The U.S. grain gift fitted into the old pattern of charity regarded with a mixed reaction of gratitude and resentment. It may be significant that once the first hangar was filled, the grain was regarded with suspicion by much of the population. Part of the grain was thought to be inferior in taste, not fit for human consumption, and infested by unknown and dangerous insects. Much of it was left to rot in large warehouses where, in fact, it still resides. Much of it was sold. After the emergency shipments had ended, AID moved to change its approach from outright gifts to the development of an integrated agricultural program. In order to cover storage and

transportation expenses, and realize a small profit for investment in agricultural development, the Government of Mali decided to sell some of the donated grains. Using the revenues derived from the sale of the donated grain, the Government formed a new enterprise with the help of additional AID funds. This enterprise is called Operation Mil. Operation Mil has as its goal the increased commercialization and production of the millet Pennissetum typhoides, in order to help provide adequate grain reserves for the rural population, help feed the cities, and provide a surplus for export.

The means by which Operation Mil set out to achieve its objectives included the introduction of modern agricultural methods of planting, the use of plows, fertilizers, and pesticides. It also included the establishment of an extension service, and the development of a rural infrastructure of wells and roads. Beyond these basic functions, Operation Mil plans to become involved in social services, and undertake literacy programs with AID funding. Profits from the commercializing operation are planned to make the operation independent of further American aid, and to permit it to continue to function after the AID financing period is terminated. Topographically, the center of the millet producing area is the plain. The soils of the plain, while fertile when manure is applied or when left fallow for several years, are subject to rapid nutrient loss from overcultivation, leading to declining yields. This danger increases with high-producing hybrid strains of millet or sorghum, which can exhaust the soil. In some cases, continued cultivation results in expanses of bare soil which do not regenerate in the normal narrow fallow period. Wind erosion then continues the process of destruction. The soil of the plains, however, make it productive for millet, and its gross potential is essentially limited only by an uncertain water supply.

Mali has a grain marketing board named OPAM, which is in charge of grain stroage and distribution. OPAM provides Operation Mil with the funds to purchase grain from the farmers ~~and~~ allows a marginal increment for transport, handling, and management, and it receives the grain from the operation. By 1975/76, Operation Mil began to commercialize large quantities of grain. The Dogon farmer stores his millet on the head inside his granaries. Operation Mil does not do so, but stores the millet in sacks, where it is prone to rapid deterioration if not properly cared for. No suitable grain-storage facilities exist for the operation. In a discussion with the Director of the AID Mission, I suggested that it would be useful to build intermediate storage granaries at the local level, in order to ensure that grain was available close to the population during drought periods; this would avoid the problems of distribution.

At the request of the Governor of Mopti, and of the Director of Operation Mil, we built an AID-financed granary at Fatoma, a village of 2,600 people, to test its efficiency and usefulness to the population. The granary was to serve Operation Mil and, at the same time, provide a storage facility for a school canteen program that was to be maintained by the population, which was planning to cultivate two fields in order to maintain a continuous grain supply for this purpose.

If the experiment proved successful, and acceptable to Operation Mil it would become the model for an extensive building program throughout the Mopti Region.

Fatoma was selected by the governor because of its easy accessibility from Mopti, which allows officials to better control and observe the storage system. Also, it is the capital of an arrondissement of 53 villages, and is considered a "village that seeks progress." Its dominant ethnic group is Peul, who have given up their nomadic existence and turned to farming millet. The granary was inaugurated by the governor in October 1975, and in March 1976, Operation Mil requested funding for 30 additional granaries from AID.

The construction of the granary took place from September 3, 1975, to October 15, 1975. It was designed by the author and Guillaume Witschi, a young Swiss builder, and built with the help of local masons and workers. Construction represented a synthesis of traditional as well as western technology. This synthesis had to be achieved on several levels in order to be viable.

On the side of modern technical requirements, I needed someone who was a specialist in cement structures, the use of pre-cast beams, stresses, etc. Considerations had to be given to fumigation, pre-drying of grain, heat generated inside the granary, humidity, and loading and unloading of grain. I found such knowledge in Witschi. Equally important would be local experts familiar with handling banco (the local mudbrick), as well as with its structural strengths and weaknesses. Fortunately, each village in the area had such experts.

We hoped to construct an un-remarkable building; we succeeded because visitors to Fatoma do not notice it among the local structures, although it occupies the place of honor in the central market. With its pointed pillars, the granary looks like a traditional mosque at a distance. The huge pillars of the granary buttress the structure and support the weight of the millet inside, and serve as welcome niches for the market women.

The granary is a large, squarish structure built of banco with a pre-cast concrete ceiling composed of tiles that sit on concrete beams. On the roof are three specially-built openings raised so that water cannot enter during the rainy season. The roof is slightly tilted, and there are the traditional water spouts of Mopti ceramic that dispose of surplus rain. A cover of banco on the roof reduces heat. The building is accessible by a large outside staircase, and the roof can serve as a platform for drying grain and weighing it during the loading period.

The granary, while built of banco, is lined with a thin coat of ferro-cement and is air-tight enough to greatly reduce fumigation costs. A humidity-proof paint helps insure the safety of the grain during the rainy season.

Inside, the building is divided into three compartments, of which the central one has a six and one-half ton capacity. This section has been set

aside for the school canteen program, while the other two compartments each hold eleven and three-quarter tons and are reserved for Operation Mil.

Loading of the building takes place through the three chutes on the roof, and unloading through three cases inside the building. The three compartments have sharply inclined floors that spill the grain into the cases where it rises like water and is simply scooped out. It uses the chicken feeder principle.

Naturally, many discussions were held with the local population before construction, and I became increasingly aware that many of the problems we were confronted with were not technological, but involved other dimensions.

The average yield per hectare in the Dogon region ranges from 330 to 550 kilograms per hectare. Since 52 percent of all land holdings are less than 2 hectares, the average farmer produces less than 1 ton of millet annually. This includes 42 percent of the total population. The land holdings are generally worked by members of the family, and, surprisingly, 42 percent of all farmland is worked by one and five persons. Land holdings are usually confined to one to two plots, and 88.1 percent of all land holdings have one to four plots per family. Lack of access to non-human energy, such as donkeys, oxen, or tractors, the fragmentation of plots, and the dispersion over a large distance, limit the possibilities for increasing production. That such increases are possible has been shown by Operation Mil working with pilot farmers. However, only 0.43 percent of the farmers have been enlisted with Operation Mil.

On the other hand, in order to obtain its necessary millet, commercialization has been increased on the basis of religiously-enforced quota systems. Quotas for millet are imposed on the villages; calculation of the quotas is based on the yield obtained by six pilot farmers in one ordinary farm. As a result, yield estimates are far too high and villages are unable to meet their obligations. Village after village complained to us that they were forced to commercialize four tons of grain when they could only produce three tons, or twelve tons when they could produce only eight tons. During the previous regime, a grain quota had been enforced by the police and the army who had entered the farmers' granaries to confiscate the grain. The situation today is better, and there is no evidence of such actions.

However, grain quotas are tied into the taxation system. When the taxes imposed on each individual are 1,900 Mali Francs, or the equivalent of 60 kilos of grain, it can easily be seen that this represents a high percentage in grain production, grain which the farmer needs to feed his family. We have calculated that the average farmer has a shortage of approximately two months of grain supply for his own consumption. This commercialization is not an indicator of increased productivity. According to OPAM statistics,the amount of grain commercialized in the 5th region from 1974 to 1975 was 13 times that commercialized in 1972. These figures reflect a trend that points to potential disaster in the future, and indicates a serious pressure on the population to sell its grain. This pressure is enforced by means of taxes. Since villagers have few alternative ways of making money, they cannot raise the money to pay the tax unless they sell the grain. As a result, they distribute the quota among themselves as much as possible, which

means that those few farmers who belong to Operation Mil have larger land holdings and are capable of selling more grain in an ordinary market and have no incentive to produce more, while those who have little are forced to sell what they urgently need. As a consequence of these policies, Dogon granaries are now empty. This situation is dangerous, as renewed drought would pose a problem for the government as well as for the population. It is therefore not surprising that villagers, when asked whether they were constructing new granaries, answered that they were not, as they had no millet to put in it. And when asked whether they wanted to have a large communal granary constructed in their village, they, in turn, asked whether it was for them or for Operation Mil. They showed little interest in having it constructed for the government because they saw the government operation as one that deprived them of the grain necessary for their survival.

The fixed price for millet to the farmer is so low (presently at 35 Mali Francs per kilo) that the investment in chemical fertilizers and plows produces little incentive for the Dogon farmer, although some of the wealthier have made a certain marginal profit on their investment. As a consequence, some farmers are becoming wealthier, whereas the bulk of the population is getting more and more impoverished. Power and wealth are therefore beginning to be increasingly polarized within the region on the one hand, yet most of the power passes to the Government. One aspect of this concentration of power becomes visible in the concentration of millet and where it is stored. Large government storage facilities are now being planned at Mopti, in order to develop security stocks in case of drought, and a base for export and for the provision of the urban centers. Such a policy, as we pointed out before, is necessary, but its consequences for the population are difficult to judge.

What then are the answers to the problem? The question of progress and the question of aid now becomes a social and moral one. We cannot, I believe, walk away from the situation. We may have to help the Mali government find solutions that will enable it to feed the cities and provide grain for export without imposing grain quotas on the population. Nothing can be a greater dis-incentive to production than quotas and empty granaries, and nothing can be more against the purpose of American aid than the support of an operation that works, even unintentionally, against the best interests of the population. Solutions can be found somewhere between the unwanted intervention in the affairs of a national government and the abdication of our responsibility to the population with whom we are working.

My recent research of post-harvest losses in Dogon granaries has shown that such losses can amount to an average of 13.3 percent per year. If this 13 percent could be reduce to perhaps 3 percent, a great deal could be accomplished. In order to do so, we may have to work not on the technology of modern grain storage systems at the national level, or even at the intermediate level, but at the level of the farm itself. Working with the farmer, we may be able to improve his traditional system by gradually introducing modernizing technologies into his granaries that will allow him to reduce losses,

while, at the same time, helping him to reinstitute throughout the area additional techniques in controlling losses that have fallen into disuse. The new package that is being introduced by Operation Mil, which contains chemical fertilizers, plows, and other modernizing equipment, needs to be evaluated, not only in terms of the increase in production that it may help bring about, but also in terms of the increased benefits to the population itself. Yet, an appropriate technology without other appropriate social policies means nothing.

In conclusion, I have been thinking of something that we might call a "just technology." A technology that distributes its benefits to the population in such a way that it will do little harm, and at the same time provide the possibility for individuals and cultures to survive (in ways in which they themselves seek refuge.) To do so, we may have to return to our own values and traditions; perhaps the vision of El Greco does provide the solution in which the giver and the receiver are identified as interchangeable human beings in a world of complex and bewildering problems.

* * *

Discussion

Q. It is magnificent that you have been able to develop facilities like those which store water in an environmentally sound manner. You have accomplished this by doing, or at least supervising, the construction of this facility yourself, or in cooperation with some associate of yours, on a very individual basis. However, such facilities are needed in almost every village and settlement. In view of this large-scale problem, do you feel that an approach such as you have taken might still be possible? Can it be done with lack of skilled manpower and funding?

A. I wish I had a better answer to your question than I have. First, I think there are enormous problems in the transfer of technology patterned after traditional methods, and, second, modern technology is cheaper. This is because traditional technology is labor-intensive and if it is used, even in developing countries, projects become expensive. On the other hand, I think the matter of advocating only modern practices are doomed to failure, particularly in remote areas. I think it is important that we maintain some connection with the traditional ways of life at this time. What I am proposing here is a new approach in which we can use certain features of modern technology and blend it in with traditional building methods and village organization. To be able to do this, one has to determine how local people can cope with new technology and how their acquired abilities can be transferred to others. I will guess that, if one wants to go and attempt to build projects like mine on a large scale, it will be impossible. We cannot get trained men even in the towns where we have been. In addition, the required materials, like cement, are usually not available; so, for an individual to build that sort of thing is quite impossible. But we are trying to determine whether there is a possibility of maintaining and propagating intermediate methods.

Appropriate Technology in the Industrial Sector

ROSS W. HAMMOND*

The selection and use of appropriate technology has been made for centuries in many places all over the world. It is only in recent years, however, that practitioners have begun to identify the process now called "appropriate," "intermediate," "adaptive," or "light engineering" with the scattered and fragmentary efforts of earlier years.

For the purpose of this presentation, I will use a definition which, like most arbitrary definitions, is intended to serve only in the context of the material which is being presented.

Appropriate technology is defined as "that level of technology which is best suited to the social, cultural, economic and political climates of the various countries of the world." This broad and non-specific definition recognizes the fact that appropriate technology usually is considered on a case-by-case basis, particularly in the industrial sector to be discussed here.

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The small and medium industry sectors in both developed and developing countries have many similarities. Generally, such industries are operated and managed by one individual, the entrepreneur, and they reflect the strengths and weaknesses of that individual. Most such organizations are financially marginal. They are undercapitalized, short of working capital, and have profit and financial operating difficulties which inhibit rapid expansion and development. The high risk nature of small industries makes it difficult to obtain new capital through conventional financial channels.

Such industries are often managerially and technically deficient, since their size will not permit the hiring of staff specialists to solve internal problems. Hence, they frequently need outside consulting help, but are rarely in a position to pay for such services.

The small and medium industries, particularly in the developing countries, usually are unable to keep up with the "state of the art" in their particular field. They do not have access to current information on changing market factors and competitive actions. There are no reliable sources of technical or alternative technology information available to them. There is no string of salesmen and manufacturing representatives calling on them to provide them with up-to-date information on products, processes, and equipment.

As a result, most developing country entrepreneurs do not really have a variety of technological alternatives to consider and evaluate. The alternatives exist in most cases, but they are not available to the entrepreneur in the developing country.

What this statement implies is that alternative technologies exist in many parts of the world, and that entrepreneurs have technological needs which the alternatives could satisfy, but that in most situations the delivery system to provide the alternative technologies to the entrepreneur is either non-existent or inadequate.

In one country in which we at Georgia Tech are involved, the government has recognized the technology transfer needs of industry and has established offices in the major cities to provide this kind of service. Unfortunately, the staffs of these offices have no vehicles, so they are unable to provide services to small industries outside the major cities. The rural entrepreneur is thus unable to benefit from the government entrepreneur. This, obviously, is an inadequate delivery system. However, in some countries there is no delivery system in existence at all, an even worse situation. So, the need for appropriate technology is not often filled in such an environment.

What then are the characteristics of appropriate technology? The characteristics as perceived by various practitioners in the field vary

considerably. There are some generally accepted characteristics, however, which I will mention briefly.

1. Technology is seldom directly transferable. More often than not, it must be adapted to different environmental conditions. As a case in point, the International Rice Research Institute (IRRI) developed rice machinery which has potential for use in many rice-growing countries. However, it was designed for wet-land rice farming, and must be modified and adapted for dry-land farming.

2. The various cultural, political, economic, and infrastructure conditions must be considered in suggesting the appropriate technology. For example, a high electric power-using technology would be inappropriate for an area devoid of reliable electric power.

3. To the maximum extent possible, local materials, manpower, and man-made resources should be utilized (foreign imports are usually high in cost, and foreign exchange in short supply).

4. Appropriate technology should encourage and foster indigenous initiative and innovation. It is not sufficient to buy technology and know-how, and to transfer and install it without encouraging, in the productive system, flexibility and a willingness to change with changing markets and other factors.

5. Appropriate technologies must have or develop logistical support systems, such as maintenance services and spare parts availability.

6. Basic to intermediate technology is the concept of cost effectiveness. Hence, most considerations of intermediate technology are concerned with labor-intensive, low-cost elements.

Let us now discuss the sequence of steps usually taken in selecting technologies appropriate to the task to be performed. These steps, as we observe them, are as follows:

1. Problem and Need Identification. The selection of appropriate technology must be preceded by recognition of a problem or a need. In Georgia, for example, the burning of peanut shells in open incinerators was adding to air pollution. This was a recognized problem, and the need was to find some way to utilize these shells in a non-polluting manner.

2. Available Alternative Technologies and Resources. Some determination of the technologies which are known and hence available must be made in the light of the obtainable materials and resources. There are many ways to build a factory chimney and a number of

different materials which can be utilized. The Koreans in Yeungdongpo Industrial Estates chose to utilize a locally available material, empty oil drums, for this purpose, and it is a cost-effective appropriate technology for that environment.

3. Analysis. Analysis of the various alternative technologies which may be available to solve a recognized problem is essential. The analysis for a developing country must consider educational, social, cultural, economic, infrastructure, and political aspects to the maximum extent possible. Lower labor costs in developing countries greatly influence the choice of technologies, skewing the selection to more labor-intensive alternatives. National plans, with their varying emphases, have a bearing on the selection of appropriate technologies. The level of education and skills of the available manpower resources obviously impacts on technology selection. These and many other factors must be considered in the analysis phase.

4. Design, Including Adaptation. Technology from the developed world usually requires modification, adaptation, or redesign when utilized in developing countries. This is particularly true in the small industry sector. The IRRI rice machinery designed for wet-land farming must be modified for dry-land rice farming. The $5,000 tensile strength tester must be scaled down, sacrificing accuracy or other characteristics to provide a low-cost unit. The tire retreading casing was modified by material substitution. Design, redesign, modification, or adaptation of technology becomes an extremely important phase of the selection and utilization of appropriate technology.

5. Prototype Development. When modification and adaptation take place, the question must then be asked: "Will it work?" To answer this question, it usually is necessary to build a prototype and to analyze its operating characteristics and performance. Our counterpart in Korea, Soong Jun University, has built four different prototypes of a "cheegay" on wheels to determine the most appropriate application.

6. Testing, Evaluation, Modification. The prototype must then be subjected to testing and evaluation. Modifications and adaptations, however small they may be, can significantly alter the capabilities and performance of the technology. Hence, prototypes with built-in modifications or adaptations require field testing and evaluation under real or simulated use conditions. Frequently, such field testing reveals operating problems which may call for additional modification or adaptation.

7. Replication (Manufacture). When analysis indicates that the prototype has been debugged and appears commercially feasible, the final step may include the encouragement of manufacture of the

prototype in sufficient volume to supply the market needs. This may involve the creation of a new venture for the specific purpose of manufacturing the appropriate technology, but, more likely, it would involve interesting the existing manufacturers in adding the prototype as a new product. The manufacturers may, in turn, adapt and modify the equipment in accordance with the specific needs of their customers. An example of this process can be seen in the Philippines. Last year, a number of existing Philippine manufacturers used and sometimes adapted IRRI rice machinery designs to build more than 16,000 units, mostly for the domestic market.

It is, of course, desirable to develop and utilize appropriate technology which may have widespread applicability. This is not always an attainable goal in the industrial sector, where problem-solving through appropriate technology is frequently location-specific, and process- or product-specific. In such cases, widespread applications frequently do not exist.

* * *

Discussion

Q. I wonder how you're put in touch with clients? Do they approach you directly or through your government?

A. We generally are contacted through our counterpart organizations. Early in the Georgia Tech program, we realized that we were not smart enough, nor was there enough staff time, to learn all about each country we might be involved in. Hence, we decided to find in-country counterpart organizations with which to work. Both Tech and these counterpart organizations learn from each other, and the counterparts provide guidance to us so we can avoid making social or cultural blunders which could impair the program effectiveness.

All the organizations we work with had small-scale industry programs before we linked with them. As a result, they receive a constant stream of requests for assistance from industry, and we assist the counterparts in responding to these requests.

Q. Where does your funding come from?

A. Initially, we invested a little institution money in developing Latin American international programs, while we were seeking outside funding. That is an expensive process for any school, but we considered it an investment in the future. As a result of Tech's domestic and modest Latin American activities, the Agency for International Development (AID) awarded Georgia Tech a 211(d)

grant about four years ago. It is the same type of grant that The University of Arizona has received, but in a different subject area. In addition, Tech has received a contract from AID to provide grant funds to 4 counterpart organizations to assist them in their small industry assistance efforts. We have had funding from a Venezuelan University, and a number of developing country governments as well, but primarily the funding comes from AID.

Q. Do these innovations become public domain, do you have them, or is there some other ownership?

A. They are public domain except in one case. The pyrolytic converter is licensed by Georgia Tech to a private corporation. This has led to some interesting problems. We conducted a feasibility study in Ghana to look at the conversion of waste wood into charcoal, oil, and gas. The design the field engineer came up with is so close to the Georgia Tech process that now we have problems with the licensee. This is being resolved by modification of the field design.

Q. Why is it that technology evolves in a natural way when the need arises in various areas of the world?

A. I do not believe technology evolves fast enough in a natural way. In most cases, new technologies must be introduced. On the developing country side, the governments are all quite interested in obtaining technology, and so in many cases governments ask for technology.

Many developing country governments are really not interested in small industry, but rather in large petro-chemical plants, shipbuilding yards, iron and steel plants, etc. It is only relatively recently that developing country governments have recognized the need to develop the small industry sector as well.

The need for outside technology exists in part because there is such a thin level of technically-qualified people in developing countries, not nearly enough to fill their needs.

Statements from Audience

* My personal opinion is that technology is developing in these countries. The only problem is that it is not developing as fast as some people would like it to. What happened is that people are trying to skip an intermediate phase in technology, and I think that's where part of the problem has arisen; the governments try to get people the most advanced technology, which they can't really handle yet, and I think what we as people who are interested in development should try to do, is increase this range as

rapidly as we possible can, keeping in mind that it's not something that's going to happen overnight. I think that, if we left people alone, technology would develop there the same way it has developed in the developed countries, at its own pace. But I think the real question is: can we afford to have development occur at the same pace that it occurred in other countries?

*I think there has to be a basis and skills and knowledge for inventions to take place. Inventions do not come out of the clear, blue sky. If you wait for invention in each of these instances, you might wait for 25, 50, or 100 years before you have people invent something which, with help from outside, they would be able to do next year.

The Appropriateness of Appropriate Technology or Can the Carabao Happily Co-Exist with the Gasoline Engine?

SIMON INCE*

The term "developing country" is commonly applied to nations which have low per capita income, high population growth rate, high unemployment, and a shortage of skilled personnel. Developing countries are, or have been, essentially raw material exporters; they have had unfavorable balance of payments, soft currency, and agriculture is the major contributor to the national economy. In the tightest definition, underdevelopment is associated with a scarcity of capital and a scarcity of strategic skills.

The objectives of most developing countries are:

a. to achieve a higher degree of economic growth;
b. to promote self-sufficiency, particularly in staple food items, in order to reach a balance of payment equilibrium;

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c. to reduce unemployment;
d. to achieve a more equitable income distribution.

It was assumed, and still is, that if these goals are met, the problems of underdevelopment will automatically disappear (note that all goals are expressed in economic terms). The achievement of the goals was, and is, often associated with the application of science and technology, in particular borrowed or imitated science and technology of the developed or industrialized countries. It is often believed that infusion of massive doses of this technology will solve the problems of scarcity of capital and the scarcity of strategic skills, and eradicate some of the chronic problems of underdevelopment: poverty, unemployment, and income inequality.

Needless to say, this policy of application of technology in the form of large water resources development projects, power plants, industrial complexes, agribusiness, etc. has, in many instances, been unsuccessful in improving the social and economic ills of these nations. It is even claimed that large-scale technology not only failed to correct these ills, but that, in fact, was responsible for the failure. One recommendation, therefore, is to concentrate on "intermediate technology," a technology somewhere between primitive and big, which is claimed to be more responsive to the social and economic needs of the developing world. Since developing country officials, however, do not always seem to share this point of view, and feel that they are being patronized, the less offensive name of "appropriate technology" has been introduced to be used synonymously with "intermediate technology."

Is intermediate technology the answer to the needs of the developing countries? Will it achieve the goals of development any faster and any better than "big technology"? It would seem that the answer depends on one's philosophical conviction, and is probably an act of faith more than anything else.

Perhaps the following examples of the application of small, intermediate, and big technology may help in arriving at a more objective point of view.

The main food of the Southeast Asian people is rice. On the average, rice contributes more than 70 percent of the total energy provided by the food intake of an adult person. With an average population growth rate of 2.5 percent per year, the demand for rice in Southeast Asia is therefore rapidly increasing. Rice is a high water demand crop, and sufficient water is available only during the wet season, which comprises about five months of the year. The dry season, however, is the better growing season because of climatological factors favoring photosynthesis and the absence of damaging typhoons.

The Philippines, a chronic rice-importing country, has the national objective of self-sufficiency in rice production, which it expects will result in a reduction of foreign exchange outflow, and a higher income for farmers, with the concomitant achievements of income

distribution and economic and social stability. All components of science and technology were therefore mobilized in the attempt to reach this goal. Today, the Philippines is fairly close to its objective of self-sufficiency in rice production. Several technological factors have played in important role in this achievement, and the analysis of some of these technologies may shed light on the role of big and small technology.

The development of high-yield varieties of rice by the International Rice Research Institute (IRRI), and the establishment of the University of the Philippines at Los Banos (UPLB), have played an important and well-known role in the increased rice production. These can certainly be classified as "application of high science and big technology."

Less well-known, perhaps, is the development and use of tillage implements and other equipment for ploughing and harrowing for land preparation, which was traditionally done by carabao-drawn plows and comb harrows.

The power tiller is a technological development somewhere between the tractor-rotavator and the carabao, and can be classified as intermediate technology. How effective has been the 6-BHP power tiller, as an instrument of intermediate technology in increasing rice production and in satisfying the other goals of development?

An agro-economic study at UPLB compares the efficiency of the cultivation energy outputs for lowland rice production for a traditional cultivating system (TCS) and a modern cultivating system (MCS). The MCS is a cultivating system in which:

a. human labor and 6-BHP power tiller were used for land preparation;
b. herbicides were used for weed control;
c. insecticides were used for pest control.

The TCS is a cultivating system in which:

a. human labor and plows and comb harrows drawn by a 5-year old carabao were used for land preparation;
b. weed control was done by hand and simple tools such as rotary weeders and sickles;
c. insecticides were applied whenever needed.

A simple economic study of land preparation for one hectare of land by the two methods is shown in Table I. These are, of course, approximate values, but indicate that the cost of land preparation is of the same order of magnitude. Which method is more advantageous depends mainly on factors such as the opportunity cost of labor and conditions of labor shortage. It should be pointed out, however, that the carabao contributes milk, meat, and good quality fertilizer with

TABLE I
Economic Analysis of Land Preparation per Hectare

	TCS 1 Man - 1 Carabao		MCS 2 Men - 6-BHP Power Tiller	
Ploughing and Harrowing	12 days		4 days	
Cost	12 man-days @ ₱*12/day	144	8 man-days @ ₱12/day	96
	12 carabao-days** @ ₱12/day	144	Rental and operation of power tiller	250
	Total	₱288	Total	₱346

* ₱ is the symbol for Philippine peso
** 1 carabao-day is the prevalent carabao rental

TABLE II
Energy Analysis of Land Preparation per Hectare

TCS			MCS		
Labor:	12 x 1.4	16.8 Mcal	Labor:	8 x 1.4	11.2 Mcal
Carabao:	12 x 19	228.0 Mcal	Power Tiller: 50 x 8.5 50 liters of gasoline		425.0 Mcal
Total:		244.8 Mcal	Total:		437.2 Mcal

TABLE III
Energy Conversion Factors

Form	Original Units	Conversion Factor
Human Labor	man-day	1400 Kcal/man-day
Carabao Labor	carabao-day	19000 Kcal/carabao-day
Fuel (Gasoline)	liters	8500 Kcal/liter
Grain Yield	kg DMD*	4000 Kcal/kg DMD
Straw Yield	kg DMD	4000 Kcal/kg DMD

*DMD=Dry Matter of Digestible Product

zero production cost, since it lives off the land. An energy analysis of the two systems of land preparation yields the results shown in Tables II and III.

In general, the results of the study indicated that the efficiency of Cultivation Energy Inputs (CEI) in lowland rice production was affected by climate and cultivating system. For a given cultivating system, one calorie of CEI input in the dry season always returned a greater amount of energy than the same amount used in the wet season.

In a cropping season, one calorie of CEI input in the traditional cultivating system always produced a greater amount of food energy than in the modern cultivating system. On the average, one calorie of CEI used in the MCS and TCS during the dry season gave a return of about 8 and 10 calories respectively, while during the wet season the returns were 6 and 7 calories respectively.

The TCS for lowland rice production was more efficient than the MCS. The CEI's in the MCS were greater, but did not give a better rice yield.

The most important factor which contributed to the inefficient use of cultivation energy in the MCS was the employment of the power tiller for land preparation.

There are, of course, advantages associated with the use of the power-tiller. Some of the benefits derived from this are better soil puddling, which will result in better weed reduction, better soil fertility, and water and nutrient conservation. Results of the study showed, however, that such beneficial effects were not significant.

The use of the power tiller for land preparation consumed an amount of energy that is twice that required by the TCS. Since it contributes about 10 to 30 percent of the total amount of cultivation energy spent for one crop of rice, it has a significant effect on the efficiency of the cultivation system.

The MCS saved a great amount of labor and time (80 man-hr/ha/crop for land preparation, 140 man-hrs/ha/crop for weeding). This could relieve a labor shortage, if there were one. It may also permit the cultivation of more crops on the same piece of land, if there were enough water and the climate were favorable. Since there is neither a labor shortage nor an easily obtainable surplus of water during the dry season, under the given circumstances the carabao (primitive technology) has a distinct advantage over the power tiller (intermediate technology).

To sum up, it is clear that intermediate technology in the form of power tiller in its present use, and within the given context does not:

a. increase the yield, and thus the income of the farmer;
b. decrease the balance of payments deficit (quite the opposite: engine and fuel have to be imported); or
c. reduce unemployment.

It may have a small part in income distribution, but only in a peripheral sense.

As a contrast, the Pantabangan Dam and Reservoir, and the Upper Pampanga River Project, an example of large scale technology, will have a great and positive impact on the four main objectives of a developing country by the provision of water during the dry season, because:

a. by the traditional cultivation pattern, a vastly increased rice crop yield during the dry season increases the income of the farmer;
b. an increased rice crop reduces the importation of rice and decreases the foreign exchange deficit;
c. farm unemployment may be reduced by intensive cultivation of a larger area;
d. a measure of income distribution will be achieved since, in the early stages of the project, the cost of water will be subsidized.

The examples cited lead to the following conclusions:

1. Intermediate technology may or may not be compatible with the objectives of development. "Big" technology may or may not be compatible with the objectives of development. The effectiveness of any technology depends on the particular local circumstances, and on whether it is augmented by fair and sensible national policies or agrarian reform, income and wealth distribution, credit availability, and other social and institutional measures. Technology by itself will not do that.

2. Any technology, small, intermediate, or big, addresses itself in general to one or two aspects of the development process. If the reduction of unemployment is the goal, then, for a given capital outlay, labor-intensive, small or intermediate cottage industries may be the answer. If, on the other hand, the increase of the gross national product is the goal, large scale industries may be more effective.

3. Slogans like "Small is Beautiful," "Big is Bombastic," and "Less is More," may be useful in an advertising sense, but do not have general validity.

4. All the good will and well-intentioned public policies accompanying the application of technology will not be enough if population growth cannot be controlled.

Finally, in response to the title of this paper, intermediate technology is not synonymous with appropriate technology. All intermediate technology is not necessarily appropriate and all appropriate technology is not necessarily intermediate. Can the carabao peacefully coexist with the gasoline engine? Frankly, the carabao doesn't give a damn!

* * *

Discussion

Q. Does the analysis made about the efficiency between the two systems take into account other inputs?

A. Yes. Fertilizer, herbicides, insecticides, and manual weeding, were taken into account.

Q. Were there any problems with the schistosomiasis or mosquitoes?

A. Other people here can tell you better. No, so far as I know, there is no schistosomiasis in Central Luzon, although there are some regions in Leyte which are experiencing some problems. Mosquitoes are, of course, everywhere.

Q. Dr. Ince, have you thought of looking at a lot of what you just said in a historical context? For example, if you look at the history of U.S. agriculture, and we talk about intermediate steps, they sort of go from pulling plows by themselves to maybe pulling with small tractors. Was that to make money, or was that to keep from wearing out people and animals? You talk about an intermediate step in this development; it is so hard to look at because we had an intermediate period, but we didn't necessarily know in advance it was coming. In other words, it was just kind of a progression. But you move into a developing country and you talk about an intermediate step; well, if we already know the advanced technology, why the intermediate step? Why not just move right in with the advanced?

A. That is a possibility. As I said, all applications have a peripheral effect; for example, in one case a fellow is wearing himself out and is subject to TB or something like that; in that case, he is better off with the use of the power tiller; on the other hand, you can also ask what the inhaling of the fumes from the gasoline engine does to him. The advantages and disadvantages, particularly outside the purely economic area, are not clear-cut. And as I said, even in the economic area, it depends on the cost of labor, labor shortage, and other factors.

Q. What is the philosophy behind going to this intermediate growth, rather than just going to very advanced? In other words, why can't you just inject a lot of big tractors?

A. That is again a question of economics and social structure. Who is going to pay for the tractors? Who is going to pay for the gasoline? Even if economically justifiable, there may be a problem of unemployment. One fellow can till all the land, and the other can sit idly by and be unemployed.

Q. You could have a maintenance problem too.

A. Definitely; a maintenance problem will come afterwards.

Q. Didn't you identify the real problem earlier in your discussion when you mentioned that there is a problem over the goals. If your goal isn't increasing gross national product, you want to go one way, and if your goal is something else, then you want to go another way. I think this is the subject that needs to be addressed. What are the goals involved? And perhaps the true goals are ones not quite so easily set in economic terms.

A. That is correct. The point is, though, I don't think we can quantify these nor can we explain them to the other countries. They have to set their own goals. If you do it for them, it doesn't work.

Q. I would just like to ask you about one rather cryptic point that you made. I think it is kind of pertinent in regard to technology, no matter what it is we bring in. It may not really solve the problems unless the population problems are solved. Is there anything that we can do in terms of technological implementation, if you will, to try to address that issue, just as strongly as we do the technology?

A. I really don't know the answer to that. Of course you can do things technologically; again, whether they will or they won't apply depends on the social and historical conditions, religious patterns, and so on, which are very hard to overcome by technological implementation. For example, I know the case of introducing free contraceptives in India, and the way it essentially failed because the midwives association went in and said they will make you impotent, whereupon the program suffered a set-back. This is the sort of thing which is not easily solved; it has to be solved within the context of the social and cultural structure of the country. Now, in many areas they are doing several things. In India, they have established a new ruling for civil service and military personnel. If they have more than 2 children and they are not sterilized they will be fired. Now, that is a high punishment in India, and is likely to bring in the desired result;

but it is only a small segment of the population; it doesn't really reach into the villages, in which having children is like having cheap labor, social security, and all sorts of things. If you cannot overcome these, then we are really not very successful. In Singapore, on the other hand, if they have more than 2 children, they cannot go to the schools of their choice, and within the context of that society this is very effective in reducing the population growth.

Statement from audience

I just remember something that Margaret Mead said once. She said that just dropping contraceptives from helicopters doesn't work!

Some Criteria for Choices of Technology for Developing Countries

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Increasingly since the 1960s, science and technology have been recognized as powerful influences in economic growth processes. Agriculture and industrial production, the discovery and exploitation of natural resources, transportation, communications, health care, education, and many

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other fields have benefited from technical innovations. This is nowhere more evident than in the developing countries, which have, in some sectors, gained enormously from the use of the technological knowledge accumulated in the developed countries. Yet, the transfer of technology to the developing countries has been accompanied by the emergence of new economic and social problems. While some of these may be inherent in the processes of modernization, others appear to be associated with the specific characteristics of the technologies which have been transferred from the more developed countries.

By the late 1960s, concern was growing over the apparent incongruencies between the goals of the developing countries, their labor supply conditions and other resource endowments, as compared to the characteristics of many of the technologies which they were importing and implementing. These technologies were characterized as using less labor per unit of output relative to traditional methods and, thus, displacing labor, or not adding greatly to job availabilities, in spite of already substantial unemployment. The new technologies also seem to be often embodied in large plants and big pieces of equipment, and, thus, appear to be relatively capital-intensive, even though capital is usually an especially scarace resource. The imported technologies appear to require the creation of large establishments, to demand new and higher levels of labor skills, to make new social demands on the countries, and to change their economic and social structures. Foreign exchange seems to be increasingly absorbed in the payment of royalties for licenses for foreign technologies and the dependency relations created.

Although the effects described are still no more than conjectures and have not been conclusively demonstrated, the potential for discordance has attracted much attention. There has been an increasing preoccupation within these countries themselves with the adaptation of technologies to the particular political and economic objectives and conditions of the developing countries, as well as in national and international lending and assistance agencies, and among development specialists. Attention has turned to the possibility of finding new technologies which would be more suitable than those presently available. However, the difficulties in specifying precisely the characteristics which would make new technologies more suitable are apparent in the variety of names which they have been given in anticipation of their discovery. These include: "labor intensive," "progressive," "capital-saving," "village level," and "intermediate." The term "appropriate" has come to be most widely used, however, recognizing implicitly, perhaps, that there are many conditions which determine the degree of suitability of a particular technology in any environment: the political and economic objectives of each country, its social structure and functioning, and the relative availabilities and qualities of its productive resources.

In the early 1970s, the National Academy of Sciences/National Academy of Engineering (NAS/NAE), through its Board on Science and Technology for International Development (BOSTID), joined the discussion of scholars and practitioners who were caught-up in the task of analyzing criteria for technological choices in development. The U.S. Agency for

International Development (AID) requested BOSTID to study the issues inherent in the concept of "appropriate" technologies.

In accordance with its usual practice, BOSTID convened a panel broadly representative of current knowledge and practice on problems of technological choice, utilization, adaptation, and transfer, to guide the study and produce a report. This was preceded by meetings of several ad hoc groups brought together to chart a course of action. These ad hoc groups were composed of economists, engineers, scientists, development administrators, and others experienced in the problems of technology transfer, utilization, and adaptation. Because the scope of such an inquiry could be very broad indeed, the panel essentially confined its attention to the industrial sector (with a brief look at the agricultural sector), and to recommendations bearing on the long-term industrialization process of developing countries. Contributors included Jose Giral of the National Autonomous University of Mexico, on appropriate chemical technologies; W. Paul Strassmann and John S. McConnaughey of Michigan State University, on housing and residential construction; Gerald K. Boon of the College of Mexico, on economic technological behavior in the metal-working industries; Charles Kusik of Arthur D. Little, Inc., on iron and steel-making; Vernon W. Ruttan and Hans Binswanger of the Agricultural Development Council, on technology transfer and research in agriculture; and Simon Teital, Mauricio Thomae, Hugh Schwartz and Jose Villavicencio on acquisition, adaptation, and technology development experiences of entrepreneurs and decision-makers in less-industrialized countries. Richard S. Eckaus, of the Department of Economics at the Massachusetts Institute of Technology, undertook the arduous task of preparing the draft for the BOSTID panel. This paper, therefore, is partly a product of the panel's interaction with Professor Eckaus over many months of study, writing, discussion, and review.

The report defines the issues involved in technological choices, largely industry-oriented, in developing countries. It describes the relations between such choices, and overall as well as sectoral development. It discusses, as well, the scope that exists for alternative decisions. By clarifying these issues, the report is intended to provide a background for the general policy that shapes the character of the many specific technological decisions that the developing countries must make. Thus, the report is not intended to be a scholarly treatise, or a comprehensive review of the literature, but rather a survey and evaluation of some of the technology-related factors available and the sources and consequences of different types of technological choices.

In the process, the panel inevitably came to a number of observations and decisions on the nature of, and potential role for, appropriate technologies in the development process. Some readers may differ with the views expressed in the report. Indeed, there were differences among the members of the panel on a number of points. However, the report should help decision-makers in developing countries recognize that technological choices are made within a political and social context, and that criteria for making choices always come at some price to any society.

The burgeoning interest in finding and implementing "appropriate technologies" reflects a recognition of the essential role of technology in development. Technological decisions and the pace of technical change affect all development processes (i.e., economic, political, and social), and, in turn, are affected by all those processes. However, there is great scope for variation in the relations among technological decisions and development processes, and little basis for a belief in technological determinism.

Economic growth is generated from several different sources and in different patterns. In general, the following economic changes are combined in successful development: 1) increases in the amount of resources available; 2) improvements in economic efficiency with which resources are used: 3) technological change that expands the potential productivity of resources; 4) changes in the relative weights in the economy of agriculture, industry, and other sectors; and 5) changes in organizational methods, with a declining role for informal and family enterprise, and a widening scope for specialization in production and exchange.

Of the many problems that emerge in the course of development, the growth of open unemployment is among the more intractable and socially disruptive. It has its sources in rapid population growth and the displacement of labor. The fundamental economic means for resolving the problems are the acceleration and improvement in growth processes, including the use of the technologies now available for the intensive and efficient use of labor. There is little evidence to suggest that major research efforts to find efficient "intermediate" technologies for small-scale village level production would either be markedly successful or contribute substantially to development.

The use of any particular technology is not an end in itself. The criterion for an "appropriate" technological choice must be found in the essential goals and processes of development. A number of different criteria have been proposed, either implicitly or explicitly. These include the maximization of output, maximization of the availability of consumption goods, maximization of the rate of economic growth, reduction in unemployment, regional development, reduction in balance of payments deficits, greater equity in the distribution of income, promotion of political development (including national self-reliance), and improvements in the quality of life. This last criterion has recently been interpreted as development by means of relatively self-sufficient village or rural activities.

These criteria are not only alternative in the sense of attracting different degrees of support, but can also be inconsistent in many circumstances. In addition, an understanding of the relationships between them and technological decisions is incomplete, particularly for the last three criteria.

There are a number of different sources of technological information and means of dissemination. These include new research and development,

transfer of existing knowledge through technical literature, specialized education, technical consulting and equipment sales, and, finally, adaptation of known methods. The available information does not demonstrate that industrial research and development organizations in developing countries have been markedly successful compared to agricultural research institutions. However, there is insufficient data to judge the relative significance, benefits, and costs of the alternative methods of generating and transferring technological knowledge.

Technological decisions are made under differing circumstances and with different motivations that affect the degree to which they achieve any of the criteria of appropriateness. Private enterprises may choose their technologies to maximize profits, but this choice will be consistent with the maximization of total national output and income only if there are perfect markets for resources and products. In actuality, markets have many imperfections, including some degree of market control through monopoly power, the segmentation of markets, and government interferences through regulations, taxes, and subsidies. In developing countries, informally organized family enterprise continues to be important, and, in general, it does not try to maximize profits in a conventional sense. Government and public enterprise can be directed to pursue any of the criteria of appropriateness, and even private enterprise can be controlled for such purposes. Yet, unless technologies that maximize profits or minimize costs are chosen, continuing subsidization from the government budget is likely to be required. The conflicting goals often posed for government and public enterprises obstruct their achievement of any particular objective.

Agriculture and the choice of agricultural technology have a particularly critical role in development, given the size of this sector in most developing countries. Much agriculture in these countries is organized in family farms whose goals are not the conventional profit-maximizing ones, and which, because of their small size, cannot engage in technological experimentation. Nonetheless, peasant farmers have been willing to adopt agricultural innovations when they are demonstrated to be profitable. There have been important innovations in agriculture in high-yielding seed varieties, intensive use of fertilizer, and mechanization. But conflicting reports of the effects of these innovations on employment and income distribution make it impossible to conclude whether, on balance, they displace labor, although in some circumstances that may well happen.

Small-scale and service enterprises appear to be relatively successful in absorbing labor. The technologies used in the latter sector seem to have greater potential for efficient use of labor intensive techniques. This may also be true of most small-scale enterprise in general; however, it is difficult to determine whether the labor intensive methods used are actually efficient.

Unfortunately, little information about the characteristics of technology is publicly available in the quantitative form necessary for policy

formation. This lack of information means that there is little reason to believe that simple and sweeping proposals for the adoption of particular types of technology will be "appropriate" by important development criteria. Moreover, no panaceas or quick remedies for the problems of development are to be found in the choice of particular types of "intermediate" technologies.

It is clear from existing studies that there are efficient technological possibilities for using more labor intensive methods in a number of sectors in developing countries. These are typically not fully exploited, in part because of distortions in the prices of labor, capital, and other resources sometimes created by misguided government policies to stimulate development. Thus, a first recommendation is to encourage the formation of resource and product price policies that will encourage the use of efficient labor-intensive methods.

While only modest expectation and resource allocations are now warranted, engineering research to attempt to extend the range of efficient technological choices would be worthwhile in order to help developing countries benefit from their particular resources. A second recommendation, therefore, is for technological and economic research that would start by first identifying the particular products and/or processes for which such research is likely to be successful.

A third recommendation is to investigate the conditions which appear to have stimulated the adoption of efficient labor-intensive technologies, and the methods for effective dissemination of information about such methods. In particular, the role of industrial and trade associations (which, in some countries, have enabled small-scale enterprise to compete successfully using relatively labor intensive techniques) should be studied.

In negotiations for the transfer of technology through licensing agreements, buyers and sellers have unequal knowledge and bargaining power. Since these negotiations may result in distorted choices and charges, the means for improving the outcome of such licensing negotiations deserve particular attention.

Decisions about technology are always specific; they are choices of particular products and production methods. The objective of the report, however, was to arrive at generalizations about the character and consequences of such microeconomic decisions.

Recognition of technology's essential role in development does not imply a technological determinism. Not only can alternative products and methods be chosen, but the wider effects of these choices depend strongly on the political and economic environments in which they are implemented. In particular, technological change is not necessarily beneficial for all development goals. Depending on the circumstances of their introduction and use, technologies that increase resource productivity may, for example, also increase income inequality, social stratification, or urban crowding.

Although there are many intuitively plausible relationships between technological decisions and economic and social development, formulating policies for introducing technology requires a deeper understanding and more rigorous definition of relations than intuition.

The conflict of contrary strategies concerning the relations between technology and development may be exemplified by the ideologies of Gandhi and Nehru. Gandhi advocated reliance on small-scale agriculture and village industry, and the technologies associated with them. Nehru, on the other hand, was responsible for the first three Indian Five Year Plans that vastly expanded the heavy industry sector using modern technologies with all their accoutrements.

Recently, there has been a resurgence of concern with the policy implementations of technological decisions under the headline of discovering and implementing "appropriate technologies" for economic development. Avoidance of widespread unemployment has moved into the forefront of economic issues in many of the developing countries. This problem is related to the rapid population growth rates, which accelerated twenty to thirty years ago, and which are now beginning to deliver massive numbers of new entrants to the labor forces of many developing countries. If the patterns of labor absorption of the recent past continue into the future, many of the new potential workers will not find jobs. That, in turn, would have important consequences for the distribution of income and wealth, unless consciously offset by government tax and expenditure programs.

Such diverse problems as balance of payments difficulties and urbanization can also be related, in part, to technological decisions. These decisions affect the relative costs and the quantities of imports and exports and, therefore, the characteristics of each country's balance of payments. In addition, patent fees and royalties for imported technologies are a direct expenditure to foreign countries. Similarly, the exploding problems of urbanization in developing countries are associated with the technological choices which affect relative sectoral development. Technological decisions in part also determine the relative expansion of employment opportunities in rural and urban areas which, in turn, affects the patterns and intensities of internal migration.

The current output of goods and services depends on the efficiencies with which labor, capital, and other available resources are used. These are determined, in part, by the technological choices made from the available alternatives. Technological choices, in turn, depend on the character of economic motivations, as well as such immediate influences as market prices of inputs and outputs, and government taxes and subsidies, as well as political influences constraining engineering and economic decisions.

The increases in output necessary to alleviate poverty require more and more resources and population growth. Technological change in the production of old products, as well as the introduction of new products,

will also account for a substantial part of the economic growth achieved. The potential contribution of technical change is related to investment rates, however, since new capital formation in many cases is the "carrier" of technological improvements. Investment must be based on domestic (either private or public) saving or foreign savings, but the substitutability of domestic and foreign saving will depend, in part, on the nature of the technologies employed. Population growth in countries with rich resources and low population density will contribute to overall growth. Whether labor force growth intensifies the unemployment problems in developing countries depends in part on the employment characteristics of the technologies employed. The education and skill requirements of the labor force will also be determined by the technologies adopted.

Though there is controversy over the most desirable patterns, changes in the sectoral composition of production are essential for development. Both agriculture and industry must grow, and if development is successful, the latter sectors will grow faster at some point to match the changes in patterns of demand which accompany income growth. The precise patterns of sectoral growth and the effects on general development goals will again depend partly on the technologies utilized.

Directly and indirectly, technological decisions will affect the processes of political development and be affected by those processes. It is only to be expected that political considerations will often dominate narrowly-defined economic goals in the choices of projects, products, and technical methods.

Since the use of any particular technology is not an end in itself, the criteria of appropriateness for the choice of technology must be found in the goals of development. These goals are concerned not only with the volumes of output and income generated by an economy, but also with the way they are produced and distributed among the population.

The criterion for choice of technology most commonly applied, either implicitly or explicitly, is output maximization or cost minimization. Application of this criterion will, in general, achieve both physical and economic efficiency in the use of resources and, thus, will do as well as possible in increasing total output. This criterion would be satisfied by the operation of private markets only if such markets function perfectly, but there are many sources and types of "imperfections."

An alternative criterion, maximizing the availability of consumption goods in the present and the future may have the same implications as maximizing growth, depending on the index of growth used. Both of the above criteria may be different from maximizing employment.

While income distribution is an issue of increasing social concern, the relations between technical decisions and the achievement of this particular goal are seldom clear. Regional development is a specific aspect of the income distribution goal. Again, technologies seldom have specific regional implications, although decisions about regional distribution will, in turn, emphasize particular sectors and particular types of technologies.

Similar observations apply to balance of payments relief, which is often set as still another alternative criterion of technological choice. It has been argued that export-oriented production will contribute more to development than import substitution. The claim is based partly on the judgments that international competition faced by export production will promote efficiency, and there is the potential of achieving economies of large-scale production by selling to world markets. However, governments appear as able to distort export patterns via subsidies and other measures as they are to create and preserve distortions in import substituting industries.

Political development has also been proposed as a criterion of technological choice. The creation of a national political system can be both an instrument and a result of an interrelated national economy in which large-scale projects undertaken with government initiative and support have a major role. By comparison, self-sufficient village-level production is more consistent with dispersed political power and decision-making, and with lower capability of the political system to evolve and respond to system demands. However, understanding of the political sources and consequences of technical decisions is still at an early stage.

Improvement of the "quality of life" has recently been emphasized, in general terms, as a major consideration for technological choice. Proponents of this criterion prefer qualities associated with village or rural, small-scale activity, self-sufficiency, minimum ecological effects, and equality in income distribution. The desirability of these particular qualities and the extent to which other objectives should be sacrificed to achieve them is clearly a matter of preference. Moreover, little attention has as yet been paid to the trade-offs among these "quality of life" goals themselves and other development objectives.

The criteria proposed for technological decisions are often competitive as well as complementary. It cannot be presumed that pursuing any one will automatically satisfy all or any of the others. Therefore, before an "appropriate" technology can be chosen, the criterion for choice must be determined and, implicitly or explicitly, other criteria must be rejected. Moreover, choices once made are not automatically feasible. If a criterion other than cost minimization is used for private or public enterprise that must meet a market test, then the enterprise is not likely to be viable without continued government intervention on its behalf. Thus, widespread use of other criteria will, in turn, require a large-scale government program of taxes and subsidies, or regulation, for the decisions to be effective.

Information about the range of available technological alternatives, their precise characteristics, and their implications for the criteria of appropriateness is essential for policy-making. Yet, such information is not readily available, and it is costly and difficult to acquire. Overall, investigations based on existing statistics yield only equivocal results, and case studies are seldom generalizable.

Although the weight of evidence suggests that most producing sectors are not restricted to a single efficient combination of resources, estimates of the range of choice available do not clearly demonstrate that wide and easy substitution is possible. Case studies, mainly in light manufacturing, do indicate that alternative techniques are being used, particularly in peripheral central production processing activities; but these case studies often do not assure that the alternatives are all efficient. Even less information is available to show how technologies satisfy distributional and other criteria of appropriateness.

Many sources of technological information exist and are used. These include some relatively inexpensive sources, such as technical literature, formal and informal education and training of individuals, as well as licensing of patented production processes, and sales of expertise and equipment. The intrinsic measurement problems and limited research make it impossible to evaluate the relative importance and potential substitutability of these sources. Information on the costs of using various sources exists, but is so limited that generalizations are not warranted. Adaptations of technology in the course of production may be one of the most common and fruitful sources of technical change, but, again, little hard information is available.

Technological choices in developing countries are made by a number of different types of decision-makers and under a variety of sources of influence. They will not all necessarily have the same objectives or conform to the same ideas of what is "appropriate." The owners and managers of both national private enterprise and international enterprise will be concerned with their own profits, but the latter will have different opportunities and constraints than the former. Both will be reacting to the incentives of the resource and the product markets in which they buy and sell. Their technical decisions will be affected by the influences they exert in their markets, and the extent to which such markets are unified and are affected by government tax, subsidy, and regulation policies. It may well be optimal for a developing country (as well as for a multi-national firm) to import technologies from more developed countries when both research and development, as well as capital and operating costs, are taken into account.

Government corporations may or may not behave like private enterprises, depending on their organization and on the objectives and controls imposed on them. In some cases, government enterprise has been used to pursue particular employment and income goals, though the pursuit has sometimes been piecemeal and inconsistent because clear incentives were lacking.

National and international economic assistance agencies, such as the U.S. Agency for International Development and the International Bank for Reconstruction and Development, may have a different conception of the development process than the developing countries themselves. They have used their loan and grant programs to advance strategies and impose conditions of performance that the developing countries may not otherwise have adopted.

The method of implementing decisions also varies among decision-makers In private enterprises, decision on technology may be made directly, but sometimes requires approval of a government licensing agency. Governments can resort to direct regulation and their fiscal system to exert influence. The official international sources of funds rely on their expertise and their power to grant or withhold funds to persuade and guide.

While technological decisions in a developing economy should be coherent and compatible with a particular set of goals, such coherence and compatibility is never fully achieved, just as it is not achieved in the more developed countries. Rather, economic policy decisions in the developing economies reflect sets of influences that, to some extent, act at cross purposes. A major task of development policy is to reduce the frustration and inefficiency associated with inconsistent goals and methods, but this task is never fully accomplished. It is especially difficult to achieve when the choice concerns appropriate technologies, because the knowledge, interests, and operating methods of the different decision-makers and sources of influence are often at variance.

The special features of agriculture in developing countries derive in part from the diversity of their production conditions. Climate and soil conditions can vary, even within relatively small countries, and the farm products and the inputs they require also vary. In addition, there is great diversity in the organization of farm enterprise. The family enterprise, as distinct from capitalist organization, is of particular importance in agriculture in developing countries. In the capitalist enterprise, labor and other resources are purchased to maximize profits, while in family farms, resources and technologies are chosen to maximize the net returns to the family's capital and labor as a whole. A number of different institutional arrangements in the formal or implicit contracts also regulate tenancy, labor obligations, and use of other resources, as well as decision-making processes. These are not all equivalent to the practices of conventional business enterprises, and require individual analysis.

The search for technological improvements in agriculture is typically centralized in research stations and is usually publicly sponsored because the scale and time horizon of the research is often far beyond what even large land-owners can afford. This centralization of technological research requires a system for disseminating results. That system is formalized in the agricultural extension services, which are also feedback mechanisms that spur research to meet farm problems.

Improved seed varieties, fertilizers, pesticides, mechanical equipment, and improved farming practices have resulted in major "revolutions" in agriculture in developing countries. When individual farmers adopt these innovations, their own interests dictate the criterion applied, just as is the case of individual enterprise in other sectors. The criterion is usually output maximization or cost minimization. However, government policy can exert powerful influences on decisions of individual farmers through taxes and subsidies, as well as through direct controls and the

provision of new technologies. Though these policies can be used consciously to direct agricultural development, their effects are often unintended by-products as farmers pursue their own interests.

There is impressive evidence that the potential for technologies to be adjusted to permit the more intensive use of labor is greater within small-scale enterprise than for larger enterprise in the same sector. However, existing studies have not yet established that this greater employment intensity is consistent with the other criteria of technological appropriateness, in particular the criterion of economic efficiency or cost minimization. Small enterprise operates in an environment with many noncompetitive elements, though their significance is difficult to evaluate. Moreover, because they typically use a relatively high proportion of family labor, and other resources not provided through markets, small enterprise does not follow the conventional rules of profit maximization. Even the continuing existence of the small firms cannot be taken as conclusive evidence of their ability to meet the test of efficiency and survival in a competitive environment.

Some types of traditional small-scale family enterprise are vertically integrated and completely transform raw materials into final products. Some small modern enterprises have specialized to lower costs and coordinate with larger enterprises. The successful achievement of this goal has been facilitated in some cases by government-assisted trade organizations.

While there are questions about the economic efficiency of small-scale enterprise, such enterprise may be successful when judged by the other standards of appropriateness. Not all "inefficient" types of economic activity are socially acceptable, but small-scale family enterprise is typically well regarded, and is frequently given special protection. On the other hand, family enterprise has also been the focus of what are now considered social abuses; for example, the intensive use of women and children in production or work in unhealthy and dangerous conditions.

The service sectors cover a particularly varied group of activities. Some heed highly-trained professionals; other sectors depend mainly on persons with little, if any, training. In the construction sector, which has a particularly critical role in the development process, a number of alternative technically-feasible technologies can often be used. Research on highway construction techniques indicates that the most labor-intensive methods and intermediate technologies are not as economically efficient as the capital intensive methods, but it may still be possible to develop alternative highway designs for which labor intensive methods do meet the efficiency criterion. Alternative construction technologies may also have different implications for the satisfaction of the criteria of appropriateness other than cost minimization.

Within the service sector, the health care delivery and educational systems appear to have important technological alternatives. These alternatives also provide different "qualities" of services, and these

quality differences make if difficult to judge the acceptability of the technological alternatives by the various criteria of appropriateness. This also is true of the marketing and storage sectors, which are considered important in the achievement of greater benefits from recent increases in agricultural productivity. The potential contributions of alternative technologies in these sectors remain to be carefully investigated.

Because of the limited amount of information and expertise on which to base policy, a major goal at this point must be to improve the knowledge base.

While many influences affect technological decisions, it is not clear how they operate and what their relative weights are. Thus, there is no single emphasis or policy that can be recommended which will insure that more appropriate technologies can be discovered for developing countries. A single-minded approach is likely to lead to decisions which are inappropriate by some important development criteria. To be appropriate, technological decisions must be tailored to the individual country, the particular sector, and the particular criterion being pursued. Village-level or intermediate technologies are seldom defined precisely, and cannot be regarded as solutions for the problems of development. There is little reason to believe that the intensive search for such "intermediate" technologies will facilitate development, and that a substantial diversion of resources to this search is warranted.

Three types of policies can be distinguished: 1) policies that improve the incentives operating in the choice of technology; 2) those that will expand knowledge of technological alternatives particularly suited to developing countries; and 3) institutional changes to improve and lower the cost of disseminating technical information.

To help make the choices of technology more consistent with development goals, the economic and political incentives operating on policy decisions should be examined carefully. Prices may not in themselves insure the adoption of appropriate technologies, but they certainly should not favor inappropriate technologies. Projects should be evaluated with correct shadow prices as well. Economic research should be sponsored to improve understanding of the technological choice process; this research should include the study of the costs of information and its relation to the exercise of influence over technological decisions, and the study of the efficiency of small-scale enterprise.

To expand knowledge of technological alternatives, task force groups of engineers and economists should be formed to generate priority lists of production methods and problems. These lists would indicate the sectors in which it was both of particular importance to extend the range of efficient techniques, especially at relatively low levels of output, and in which research would have reasonable opportunities for success. Research to actually explore toward new technologies should then be supported on the basis of the priorities established.

The general presumption should be that technological investigations should be done in close conjunction with the potential users of the technologies. Technological information should also be accumulated and disseminated with careful attention to the evaluation of its quality and its economic as well as technical implications. Research should also be sponsored to improve the understanding and effectiveness of the public and private mechanisms customarily used to collect and disseminate technological information.

Although institutional conditions are important in the determination of technological choices, these factors are not well understood, and research in this area needs to be expanded. For example, the role of trade associations and government standards in expanding and modernizing small-scale enterprise should be investigated. While technological decisions and political factors are interdependent in development, these interdependencies also deserve more study.

Consideration should be given to finding means for improving the terms on which technological licensing is done. At present, there is some degree of monopoly power in the differential possession of technological information and project-by-project bargaining. Thus, existing licensing methods can be expected to lead to inefficient uses of technological information.

Since technological decisions affect the pattern of all development processes, they may, to some extent, be consciously used as instruments of policy to affect the course of development. Recognition of technology's essential role and its potential as a policy instrument has been implicit in the recently burgeoning interest in implementing "appropriate" technologies.

The only standard for deciding the "appropriateness" of technological decisions is reference to the general goals of development. The qualities of technology are not more or less desirable in themselves, but only for their output potential, their corresponding input requirements, and their effects on social and political organization. In particular, small-scale or labor-intensive technologies are not necessarily "appropriate" because they are small-scale or labor-intensive. Whether they are appropriate depends on their ability to contribute to development objectives. Only if inherent features of technology dictate other patterns of life and development can technology be treated as an end rather than as a means. While this possibility must be considered, the resolution of the issues involved should not be prejudged by adopting this view. The alternative viewpoint is that, although technological choices have broad economic and social implications, a technology seldom has inevitable consequences that dictate a particular pattern for the economy and society. Many economic and political instruments can, in principle, be used to guide and modify the impact of technical decisions. However, this viewpoint also requires critical examination, since there may be many circumstances having undesired effects on a particular technological decision.

* * *

Discussion

Q. I think you made the comment that technology transfer is not related to an improvement in the employment picture. Is that, in fact, what you said?

A. What I said was there is no clear-cut relationship between the two. I suppose there has been more written on that particular aspect of appropriate technology than on any other. Five years ago, when we started this study, an analysis was made by development experts that concluded that all you need to do to alleviate the unemployment problem in developing countries is the proper selection of the technologies which would absorb these people. For instance, the World Bank started a project to determine whether you could use large numbers of people for building roads. Instead of using tractors and buldozers to build the roads, they had people use baskets and carry things on the tops of their heads; rocks, soil, and so forth. They found that it required more energy to feed these people than the savings resulting in using labor intensive methods. It would have been better to just give them a goal in terms of the wellbeing of those people. So, what I am saying is that whether you can choose technologies to absorb large numbers of unemployed is just not verified yet.

Q. Doesn't that get back to what your goals are?

A. It's how you choose, that's exactly the point, yes. What I am trying to say is that it is misleading to try to state that you can choose a certain technology, or at least that we know how to choose certain technologies which will absorb these and still be a productive sector of the economy and the developing process. Have I confused you? This is a little bit like the argument, that, since it costs approximately $25,000 a year to keep a man in business, let's give all the crooks $25,000 if they promise to behave!

Q. I may be mistaken in what you said, but it is my understanding that you tried to establish one plan to work in over a hundred different developing countries.

A. No, I don't think we tried to establish any one plan for anybody. All we tried to say is that people in each country have to sit down and take a look at the criteria of choices of those technologies, and then decide how do they go about making decisions which would select those technologies, and how they find what technological choices are available. They then define the relationships between the two, and the trade-offs that may or may not be complimentary. In fact, it may be the opposite of what some of the choices are. I don't think that I even suggested that anyone use this as a development plan.

High-Level Technology

Remote Sensing and Developing Countries: Potential and Problems in the Transfer of a Technology

LEONARD BERRY*

The first hand-held camera photos of the Earth, taken in the 1960's, made a dramatic impact. Many of us saw for the first time the unity of the environment of our small planet. We knew it in our heads before, but now we could see it. The total impact was immeasurable, but its significance is beyond dispute.

By 1972, technology had moved on, and the Earth Resources Technology Satellite (ERTS I) was launched. There were also a number of meteorological satellites by then. ERTS I, with its electro-optical imaging system, views with its multi-spatial scanner a strip of the Earth 194 Km.wide. Four color filters divide the incoming light into different wavelengths. In ERTS I, two visible and two infrared bands have been chosen to highlight features of the natural earth. Using the four bands, the range of features from

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solid rock and buildings to natural and cultivated vegetation, all can be highlighted as they each emit distinctive signatures for the sensor to detect. The various signals are put into digital form, and recorded on magnetic tape.

Photo-like images are readily reconstructed from the tape using false color, though it is also possible to abstract data directly from the tape once the identity of the particular signatures has been decoded.

At present, ERTS I (renamed LANDSAT I) has been joined by LANDSAT II (in good time, as ERTS I was experiencing failure in a number of components), and, in addition, the Skylab project also included a number of experiments involving remote sensing.

So, in the last few years, scientists have been subject to a flood of data incorporating another new and different view of the Earth. Not just the dramatic view of the Earth from space, but a carefully orchestrated flow of data available for each spot every 18 days. The view is far enough away to see "most of the elephant." It is close enough and precise enough to provide a quite different perspective on many aspects of the Earth's natural resources. It is important to remember that the work so far has all been in an experimental mode: NASA has put up the satellite and made the data widely available at reproduction cost to a diverse range of users. The limits of currently-used technology allow resolution only to about 80 meters, so security problems have not arisen in the reproduction and availability of the material.

This presentation attempts to review the impact that this new kind of data is having on developing countries. It tries to review, through examples, what is happening at the present time, and, more tenuously, it provides an assessment of the possible potential and problems for developing countries in the coming years.

Some technologies are in use for many years in some parts of the world before they slowly diffuse to other areas. Nuclear power generation technology is an example, even though its diffusion may be too fast for some. But, within three years of the launching of ERTS I, the imagery was being used in over 100 countries, including Eastern European nations, many countries of the developing world, and China. Large investments in receiving stations have been made in Canada, Italy, and Zaire, and many hundreds of people have taken courses on how to use the output. ERTS/LANDSAT has become important to the professional lives of many individuals, to the operation of many companies, and to the resource analysis agencies of many countries. This may be, in part, a result of the variety of kinds of product available from the data, but I can think of no other technology which has become used over such a wide area in a short period of time. This level of adoption is particularly impressive when one considers that there is no real certainty of its continuation. There are currently no firm plans beyond the launching of LANDSAT III in 1977. There have been

hard evaluations of the utility of the program, and its cost effectiveness. Critics have doubted its scientific worth in the U.S., and have questioned its continued funding once the experimental phase is over.

Because of the widespread use of ERTS/LANDSAT, and the uncertainty factor, there has been extensive discussion in the United Nations and elsewhere on future alternatives to the U.S.-funded satellite. The Dutch have suggested the possibility of a satellite geared more to the particular needs of developing countries, and the U.N. Committee on the Peaceful Uses of Outer Space has seriously considered ways of internationalizing the satellite part of the project in a long-term earth sensing system. Within the U.S., a National Academy of Sciences Committee has just completed its discussion of this problem.

It is relatively easy to judge how many countries and institutions have obtained imagery or digital data, as there are few centers for the dissemination of this material; it is more difficult to find out the full range of uses made of the material, though several useful reviews have been conducted.

A study in early 1975 concluded in part:

> There is a broad range in the level of awareness and status of remote sensing activity among various developing countries, ranging from those with considerable advanced programs, including numerous remote sensing activities, to those exhibiting little or no awareness of either the technology or its potential for their national development. Transfer of remote sensing technology appears to have been more actively pursued and consequently more thoroughly affected in Latin America than in either Asia or Africa.

Where remote sensing is just being introduced, it is most likely that its use is in the form of visual images. In more experienced centers, the use of tapes and associated computer technology is more likely.

The range of uses of the material in developing countries includes:

<u>Mapping</u>: as the images produce a near perfect representation of the Earth, large scale features can be mapped without the major distortion correction. For remote areas, the first ever accurate maps have come from ERTS/LANDSAT images.

<u>Land Use Analysis</u>: the 80 m. resolution creates problems for small-scale tropical agriculture, but more and more is being gathered from the data as interpretation skills increase.

Mineral Deposits and Geological Mapping: detection of large-scale features aids major mapping, and has helped in identification of important mineral resources.

Structural Analysis: analysis of rock structures assist not only with mineral location, but also in identifying underground water resources.

Population Changes: in rural areas, through land use changes; in urban areas, through analysis of urban growth.

Agricultural Inventories: especially for crops occupying large areas.

Surface Water Resources: rivers, lakes, ponds.

Regional Planning: in Egypt, for example, particularly where new settlement and irrigation projects are underway.

The kind of material used most frequently is illustrated by images of Kenya and Ethiopia. These false color transparencies provide a comprehensive view of large stretches of Kenya, and, for the first time, allow a look at the inter-relatedness of Kenyan natural resources in a graphic way.

For example, an image of the northern rift valley shows clearly an unusual color for lake Baringo, where silt-laden waters have produced a quite different image than the relatively silt-free waters of the other rift valley lakes. The source of the sediment, which is destroying the fishing and tourist industry in the area, is the over-grazed and denuded area south and west of the lake, also clear on the image as is the small irrigation scheme which attempts to provide an alternative form of land-use in the area.

A Mount Kenya image provides another sharp picture of this fertile volcanic mountain with high altitude forests, its ring of densely-peopled and intensely cultivated foothills, and the drier, eroding land beyond. This image illustrates very clearly the context of de-development in this environment.

Another image shows a drier, harsher environment in southern Ethiopia; this is a semi-arid environment, with the high status vegetation confined to the flood plain, and grass and shrub elsewhere.

Each of these images, and the tapes of which they were made, provide a vast store of information. As repetitive images are available every 18 days, and cumulatively over a period of years, quite

new vistas of resource information are opened. How can developing countries handle this data flow? Is it of real use to them? How do they find out? These and a host of other questions must be asked at the receiving end.

Up to the present, most emphasis has been on the use of ERTS/LANDSAT imagery for the collection and analysis of data on natural resources. Natural resources are important to the development programs of most countries. Indeed, a case can be made that natural resources are more significant to the progress of developing countries than they are to more industrialized societies. In many industrially-advanced nations, with their accumulated capital and sophisticated technology, economic life is dominated by finance, distribution, and services that make relatively little call on natural resources. Developing countries, on the other hand, must depend much more on what they do with their natural resources, in agriculture, mining, and the processing of their materials into industrial products.

According to a 1970 U.N. report, "the process of economic development consists largely of organizing the development and productive exploitation of natural resources in the interests of the whole community.* But before a nation can move effectively in this direction, it must know what resources it has, and where they are. The knowledge in developing countries of the extent, location, and state of their own resources is limited, fragmentary, and, on the whole, less than adequate for the purposes of sound national development.

Clearly, a major task in most developing countries is to acquire, analyze, and utilize the natural resource information needed to promote their development. The nature, scope, and volume of the information required will vary greatly from one country to another.

The nature, volume, and particular mix of the information needed by individual countries may be determined by a number of factors, including:

1. Size of country. A country with a large area and a large population will obviously need, not only more, but different types of information than a country with a small area and a small population, or both.

2. Resources endowment. The known resources of a country, as well as the resources that are discovered as a result of information-gathering activity, will point to the geographic, geologic, and economic sectors that require further study and exploration.

3. Available information. Some countries have a paucity of useful resource information across the board. Others have a

*Natural Resources of Developing Countries: Investigation, Development, and Rational Utilization. Report of the Advisory Committee on the Application of Science and Technology to Development. Department of Economic and Social Affairs, United Nations, New York, 1970. Page 5.

substantial volume of information in certain fields, and significant gaps in other areas. Nations that were formerly in the British sphere, for instance, usually possess good geological surveys, but have some catching-up to do in soil surveys.

4. Development goals. A sound base of resource information ideally should be an important component in a nation's development strategy. However, regardless of how the goals are arrived at, the development priorities which have been decided upon will determine the type and quantity of resource information they need for immediate development purposes, and what will be useful to have for longer-range national objectives.

5. Absorptive capacity. The level of a nation's development at any particular time will determine how much resource information its planners, managers, and decision-makers can usefully assimilate and apply. The type and volume of information sought should bear a reasonable relation to the availability of professional expertise to handle it, and the capacity of the nation's institutional structure to make effective use of it.

6. The cost factor. Data gathering for development has to be paid for, either by governments of developing countries themselves, or by donors of bilateral or multilateral aid. The amount of resource information it is possible to gather is virtually endless, with costs one of the limiting factors. Data gathering has to be looked at as an investment in development, recognizing the waste implied in gathering unusable data, a risk that must be calculated against potential profit or benefit. Nations or donors have to decide whether to apply cost-benefit calculations narrowly to the information needed for immediate development objectives, or to provide as well for an information base that will be needed to identify future developmental opportunities or environmental problems, or that will be useful for future scientific advances.

It is not surprising that ERTS/LANDSAT imagery has been examined closely as a means of rapidly overcoming data deficiencies in some developing countries. It has been given particularly close scrutiny in countries where there is a combination of high technical skills and large areas of little-known country. Brazil, Bolivia, Peru, and Egypt are examples of countries where the imagery is seen as an important aid in the development of under-used lands, and in the improvement of the data base on those areas. In Bolivia, for example, all types of data, including computer compatible magnetic tapes, are being used by local personnel, and remote sensing is helping in geological surveys, census mapping, topographic surveys, and analysis of land-use at a national level.

In other countries, the data is currently being used only in the form of images, and, most frequently, by foreign consultants or expatriates.

However, we have enough information to gain some insight into the possible impact of remote sensing or information gathering and data flow. The benefits and potential benefits are clear but there are also problems.*

First, remote sensing interpretation has been more effective for natural resource data than for human resource information, although increasing attention is being given to the latter. One result of this is that the use of remote sensing creates or exaggerates an often existing imbalance of information. In many cases, much more is known of the physical aspects of natural resource use, and relatively little on the agricultural and other livelihood systems in the area. Such an imbalance is not new and has been a major problem in development planning for the last two decades. The typical river basin development survey has included a thorough analysis of hydrology, soils, vegetation, and the like, and a much more cursory analysis of people. Local skills, local knowledge, and local aspirations have not been taken much into account in planning such programs. There is a danger that the uncritical use of remote sensing can exasperate this dichotomy.

A second problem is the tendency for all involved in the analysis of remote sensing material to proceed rapidly from the relatively straightforward analysis of false color prints towards the use of more sophisticated magnetic tape and computer analysis. This may be an easy transition in some countries, where both skills and financial resources are available, but, for most developing countries, a considerable part of potential impact can come from the use of fairly simple techniques. In many countries, the greater benefits involved in the use of sophisticated analysis methods are counterbalanced by greater costs, problems of equipment maintenance, training, and keeping the personnel to perform the operations, etc., etc. The goals of the individuals involved, and the objectives of the companies involved, may not coincide with the needs of the situation.

Earlier in this paper, the impact of remote sensing technology on individuals and companies was mentioned. In addition, and equally important, it is time to analyze the impact of remote sensing on institutions.

Most developing nations have institutional frameworks very similar to developed countries. In fact, many of these institutions have been transferred through colonial or other diffusion processes, and have since undergone varying degrees of modification.

The government structure is commonly organized in ministries, "departments" or "secretaries." Typically, there is a Ministry of Agriculture, a Ministry of Power, a Ministry of Lands and Surveys, a Ministry of Natural Resources, a Ministry of Tourism, each with distinct

*This section was partly based on a chapter in the forthcoming National Academy of Sciences report "Remote Sensing and Development."

hierarchies and separately-defined responsibilities. Soil studies are often the responsibility of the Ministry of Agriculture, geological surveys in a separate survey department often attached to the Ministry of Natural Resources, or even the Ministry of Industrial Development; land surveys are in a Ministry of Lands, forest resources in a Ministry of Natural Resources, and so on.

Development planning is usually coordinated by a Ministry of Economic Planning, though there are also planning units in many individual ministries. Economic planning is most often a centrally-conceived and directed operation, mostly using economic data in statistical form. Although such a ministry is organized to coordinate, it is not most often oriented to coordinate natural resource data.

In addition, many countries have a National Council for Scientific Research, which might be thought of as more appropriate as a home for remote sensing technology. In a similar way, educational systems are well organized to examine the intricacies of the separate disciplines, and not well organized to bring those concepts together in a comprehensive way.

Institutions are thus geared to a separate examination of each of the components of natural resource systems, while the nature of the remote sensing technology provides every incentive to an integrated approach to these issues. The imagery in particular, provides an integrated view of environment and resources linking soils, vegetation, geomorphology, structure, and human land-use. While an analysis often separates some of these components, concentrating on one or more of the parts, the comprehensive system is there. If work is carried out in a coordinated framework, one piece of data can help to illuminate another. A systematic approach to remote sensing data analysis is thus most rewarding.

Given this apparent conflict, it is significant to first examine the way in which remote sensing technology is being used institutionally, and to then look at the possibilities for the future.

In a number of cases, developing nations have set up separate centers for remote sensing technology, which are charged with coordinating with ministries and other institutions. These centers are often the result of individual initiatives. In Bolivia, for examples, the Programa del Satélite de Recursos Naturales was initiated in the Servicio Geológico de Bolivia in response to the possibility of mineral discoveries (in fact, a number were made), but rapidly grew in sophistication and coverage so that now the center carries out many other studies, including work on resources of less-populated areas, national maps of land-use, a study of population density and population change, mapping of census boundaries, and topographical mapping, as well as the original geological and structural studies. In these cases, the technical skills in imagery and tapes analysis are being used in a variety of disciplinary fields. The knowledge gained from one analysis, land-use for example,

is of great help in boundary mapping. Within the center, it seems likely that close integration of studies can be maintained. The major problem might be integrating remote sensing with activities in other ministries and departments.

In Egypt, the National Scientific Research Council has taken the lead in coordinating remote sensing technology, and here the scientific research mode has been dominant up to the present. The work carried out by the center includes construction of land-use, geological, and drainage maps, analysis of ground-water potential, soils, and potential for mineral development. The three research groups in geology, agriculture, and physics work in a coordinated way, yet link with particular ministries and agencies in the government.

In Kenya, a different pattern has emerged. Kenya is a country with a number of coordinating bodies, including an Environmental Secretariat, and an inter-ministerial coordinating council for land-use problems. Yet, the use of remote sensing has taken place through Ministerial structures. Remote sensing is being used in the soil survey, the geological survey, in the United Nations Environment Programme, and in the central statistical bureau. There is currently no comprehensive coordination of these activities, though there is informal cooperation between several of the groups.

The way in which institutions develop may be an important factor in delimiting the character and extent of remote sensing use in coming years.

Remote sensing can be thought of as a new tool which can be of great help in interpreting resource information. In time, it might, under this viewpoint, find its way into the operating procedures of most conventional agencies, and they would, it is implied, continue to operate on a sectoral basis.

Another viewpoint would emphasize the innovative capacity of remote sensing. In this analysis, we have to ask what new opportunities has remote sensing made to enable a redefinition of our whole concept of data gathering analysis and use, not only for natural resource planning but for the whole development process.

So far, remote sensing has been used in developing countries mainly as a means of assessing and analyzing data in a static way. It is proving of major help in this activity and will, for the foreseeable future, continue to be used in this way. But the greatest impact will come when full advantage is taken of its use in monitoring. Linked with high altitude photography and appropriate ground studies, remote sensing provides entirely new possibilities of monitoring many aspects of the changing world's surface.

At a national level, many developing countries are very interested in obtaining better information on:

a) Crops: although the scale of most indigenous tropical agriculture makes some monitoring difficult, the new generation of remote sensing technology will enable monitoring of most crops.

b) Forest and woodland depletion: changes in flooding patterns or major rivers; desertification and other changes in grazing land; changing patterns of land use; population growth in rural and urban areas; coastal and lacustrine pollution.

In addition, there is increasing demand for monitoring of some or all of these factors on an international basis.

For many developing countries, such new flows of data will need to be matched by changes in analytical capacity, and in the receptivity of planners and decision makers to this kind of information. It is not likely that any uniform use pattern or institutional pattern will evolve, but it is clear to me at least that important roles exist for government, private enterprise, and university and research type institutions.

One type of evolving system might be a specialized type of institute, perhaps within government, perhaps as a para-state or semi-private body, linked with a university. This could provide the coordinated analysis that is necessary. But it is also important that remote sensing analysis should be closely linked with the decision-making parts of government, maybe both with any central economic planning ministry and the individual sectoral ministries.

An additional question that needs more extended discussion than is possible here, is how can remote sensing data be linked with local systems of "on the ground" knowledge. A combination of indigenous ground-truth and the all-encompassing satellite view would make a powerful combination for most development purposes.

In concluding this brief review of a wide ranging topic, it is a salutory thought that the style of the use of remote sensing technology may greatly influence whether it is just another useful tool for the "experts," or a catalyst for new patterns of data gathering and development planning.

* * *

Discussion

Q. Have the political fears about remote sensing held up its use, or does it seem to be taking hold? Are they following-up on this?

A. Yes, I can illustrate a couple of things. In some countries, remote sensing was looked upon with a great deal of political

suspicion in the early days. People were really, really critical in Tanzania, for example. That's changed, and it's changed so much that an American company was brought in to produce an analysis of part of the northern area of Tanzania, the Arusha area. Part of that process was a training program for Tanzania personnel in Canada, and that program is still underway. In addition, the Bureau of Resource Analysis in Tanzania has used the imagery in Rukwa, an area in the south. It has become much more accepted in the past 18 months than it was previously. One of the problems that comes with the technology-oriented companies is that they are well-equipped to do the technical aspects, but a strong national group is needed to work with them and follow through on some of the local aspects, not only just in finding out where these people want water, for example, but finding out how much and of what quality. There are a lot of things that one can only get from interpretation from local expertise.

Q. Is this perhaps an example of a contract which maybe should have been the training program for barefoot local interpreters, so to speak?

A. Yes. I have been impressed ever since I was working in Sudan with air photographs about 20 years ago, and my illiterate driver could find his way on the air photographs. If I say "as well as I," then I am doing him an injustice. It is the same with the imagery. You don't need to be literate; you can get a lot out of it by knowing the ground and realizing what an image of the ground is.

Q. The guy that knows the ground probably gets more out of it than the highly trained technician.

A. I would agree with that, yes. The other country, Botswana, is an odd place because the Botswanian civil service is still at middle level, very heavily expatriate, and they have got a very high use of imagery for all kinds of things. They are using it, for instance, for looking at bush fires. You know, the Kalahari Desert is a very large part of Botswana, and it has had very wet years recently, and the grass has grown very well, but the problem is that burning has become a major issue. Using the repetitive cycle of the satellite, you can look at, not only the amount of burning, but when it appeared and how far the individual burns have traveled. There are some horrifying figures. One burn that we looked at traveled 60 miles in two days. Remote sensing is very well used, but it is still essentially a non-indigenous bureaucracy that is using it. However, it may very well be passed on to the Botswanans as they get into the bureaucracy.

Controlled-Environment Agriculture and the Developing Countries

WAYNE L. COLLINS* AND CARL N. HODGES*

Agriculture is believed to have begun 8,000 to 9,000 years ago with the deliberate cultivation of crops. History has since been milestoned by a series of critical breakthrough points, each representing a new technological advance in agriculture which has increased food production by reducing or making more effective the human labor required. Four thousand years ago, wooden plows replaced digging sticks. Two thousand years ago, iron plows replaced those of wood, and in the 10th and 12th Centuries A.D., animal power and wind power were utilized to till the land and pump irrigation water. In the 18th and 19th Centuries, animals and windmills began to be replaced, in turn, by steam power and the internal combustion engine. Particularly in the U.S., the increases in technology and in production, with reduced requirements for human labor, steadily eroded the rural population. Two generations ago, one American in every four lived and worked on the farm. Today, one American in ten

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is on the farm, and yet agricultural production has vastly increased and the bulk of the population has been freed from food production to pursue other objectives and lifestyles.

It is possible that controlled-environment agriculture (CEA) is another of the critical milestones in the history of food production, and it may play a significant role in regard to developing countries. Let us examine what CEA is, what the world food problems of today are, and how the first may impinge upon the second.

CEA is, in a word, greenhouses. The technology ranges from the simple shading of plants to reduce temperatures during periods of excessive solar radiation, through the whole spectrum of conventional greenhouses, to the highly advanced systems of temperature, water, and nutrient-controlled food production centers of the type designed by the Environmental Research Laboratory, and now in operation in various geographies of the world. For purposes of today's discussion, CEA means the latter; large, modern greenhouse structures, where all basic parameters of plant growth are rigidly controlled, where year-round growing seasons increase production over open field agriculture by factors of ten to forty, and where cropping schedules may be timed precisely to coincide with the most favorable market prices. There are significant savings in irrigation water, and the effects of fertilization become much more cost-efficient.

CEA is obviously capital intensive. Dependent upon design requirements, it can also be energy and/or labor intensive. A successful commercial application of CEA is therefore extremely site-specific, and there are not many such installations today which can be categorized as successful. Indeed, there are not many applications of CEA, successful or otherwise, in total world agriculture. There are a few thousand hectares of greenhouses of any kind, particularly in Europe. Compare this to the total amount of cultivated agricultural land, which is estimated at 1.4×10^9 hectares, and it becomes apparent that CEA can hardly yet be described as an agricultural revolution. It is today not only site-specific, but it is limited primarily to crops of highest economic value, principally such table vegetables as tomatoes, cucumbers, and lettuce. Although the basic agronomic crops do very well in CEA (they have all been tested),there are no such commercial applications today. The constraints are economic, not technical. Given today's prices for materials and energy, there is simply no way to grow rice or cereals in CEA and recover the investment. It therefore follows that CEA, while technically capable of feeding a hungry world, is not about to do so because of the realities of the marketplace.

This gives us a feeling for what CEA is, and, as importantly, what it is not. To determine what roles it may play in developing country applications, we must now review the basic problems in world agriculture today.

The first of these problems is the basic world demand for food. Despite the attitudes of many of us in affluent societies, famines remain common (there have been dozens in the past two decades), and, at this moment, an estimated 460 million humans are starving or nearly starving. It is estimated that, within three years, the world food shortfall will be somewhere between 32 and 188 million metric tons. And yet, astonishingly, total food production more or less matches total world demand, and will still be doing so in three years. The problem is not production, it is maldistribution. Some places do not have enough food, although places around them do. Some times there is not enough food, although there is a surplus before and after those periods. Some people do not have enough food, although those around them have plenty. And foods for proper nutrition may not be available, although there is food available. It is the raw needs of the poor that are not being met. The causes of this maldistribution almost defy understanding, let alone problem-solving. The causes are institutional, economic, geographic, demographic, political, logistical, and climatological.

What can CEA do about this problem?

Well, CEA can vastly intensify production, and do so with great flexibility of locale. It can grow the food where and when it is needed, even in deserts, using less water and less land. It can increase yields, produce more crops per year, and greatly reduce losses due to pests and weather. Indeed, CEA could so massively increase total world food production, if there were no constraints upon the technology, that we could support a world population many times larger than today's without any difficulty at all. This, however, will not solve the problem of maldistribution posed by economic inequities.

Meeting the demands of the poor is a problem for the social scientists, not for technicians. CEA produces food, but it does not produce cheaper food. Governments must make policy decisions to feed the poor at no cost, in which case CEA can provide it, or must take steps to increase the economic power of the poor, via regional development projects. CEA itself could represent a productive, government-aided regional development project, providing not only food but the capacity to buy it, through job opportunities and the generation of cash income. The thought of regional cooperatives is not too far-fetched, as most of the labor and skill requirements of CEA are not demanding.

The second major problem of world agriculture is the challenge of increasing production and conserving resources. The common indicator of productivity is, of course, crop yield. The factors influencing yield enhancement generally are irrigation, labor, machinery, and energy inputs (particularly in regard to fuel, fertilizer and pesticides). The major contemporary difficulties with such yield increasers are that

their costs are not stable and the return on increased investment is incrementally diminishing. Increased fertilization, for example, gives proportionately greater yields only up to a point, beyond which additional nutrients give smaller and smaller increases, collapsing the cost-benefit ratio. Further, the perils of depending upon fossil fuels for feedstocks and operating energy are increasingly apparent. Indeed, the arbitrary price increases in fossil fuels have had profound effect upon the costs of virtually all agricultural inputs, including replacement parts and supplies.

What can CEA do about this problem?

Well, CEA does have a beneficial effect on some of these difficulties, although its overall impact is uneven. Certainly, CEA eliminates land availability as a constraint against increased productivity; it requires only a tenth as much land, and the quality of the soil is unimportant. Certainly, CEA requires less irrigation water, which is important in itself and has the additional benefit of reducing energy requirements for pumping and purification. Certainly, CEA makes more efficient use of the fertilizers and pesticides required, although some restraint is advised in reviewing the numbers. For example, CEA generally may be said to require only two-thirds as much fertilizer as open-field agriculture, but it also requires four times as many applications. And while lesser amounts of pesticides may be used with greater effect and with no environmental pollution, the relative ease of application is a temptation to the operator to use pesticide control with much greater frequency. The costs of machinery and human labor are site-specific for CEA (which may be designed to be more intensive in either, as a function of regional availability and costs), but, in any event, are more efficient in CEA than open-field applications. Energy inputs are also site specific, but CEA obviously requires more, especially in regions where winter heating or summer cooling is necessary. And the costs of metal and plastic parts is many times greater in CEA.

A significant and yet easily overlooked benefit of CEA in increasing productivity is the selective use of some of its components in conventional open-field agriculture. This may be one of CEA's greatest contributions to developing countries today. For example, great benefit could come from the establishment of a CEA greenhouse as a nursery or seedhouse, to carry a region through a drought or a plague of insects, or prepare material for transplant to get a jump ahead of the normal growing season. Another example is the use in advanced open-field agriculture of the drip irrigation systems and fertilizer injection systems developed for CEA.

A third major problem in world agriculture is reliability of production, and reliability of ultimate consumption. Any farmer knows that agriculture is a chancy business. He is at the mercy of weather, pests, and diseases. This problem is acute in the developing countries, where

such natural variables may wipe out more than half of all crops, but it is by no means limited to developing countries; even the most advanced agricultural nations are affected. Worldwide, these natural unreliabilities cause annual crop fluctuations in the field of 10 to 15%. Worse, once harvested, a significant percentage of all crops is destroyed or contaminated in storage by rodents and insects. In some African countries, the crop destruction in storage is as high as 100%. Many farmers throughout the world try to anticipate these losses in the field and in storage by overplanting. This sort of crap-shooting is seldom effective, in the sense that, if it does work, that is, if weather and pests and diseases do not wipe out the crop, the farmer may get a bumper harvest, as a result of which he depresses market prices and does himself as much harm as good. Governments have developed mechanisms against the unreliability of production, principally commodity stockpiling and crop insurance. Commodity stockpiling has advantages during periods of over-production when, at least in the growing region, the concept is applauded. But during periods of short supply, when the pendulum of reliability has swung the other way, stockpiling generates extreme moral controversy. The idea of crop insurance,which is less common in the U.S. than in other agriculturally developed nations such as Japan, may be a more useful mechanism in developing countries. Crop insurance cannot avert or correct actual food shortages. But what it does do is encourage farmers to accept greater risks in food production, in the knowledge that, if they are hurt badly or even wiped-out, they have not lost everything. The government has backed them up.

What can CEA do about this problem?

Well, to a great degree, CEA frees the grower almost entirely from the unreliability of weather, insects and disease. He knows what his losses, if any at all, are going to be. He can time his production, and harvest his crop at the times of greatest scarcities, giving him a maximum return on his investment, and, at the same time, greatly stabilizing the total pattern of supply and demand. Such a farmer is not constantly exposed to the threat of overnight economic catastrophe, and will require a minimum of government support, subsidy or insurance. This is an extremely significant advantage.

The fourth and fifth big problems in world agriculture we will consider simultaneously in the interests of saving time: protecting the environment from damage by agriculture and protecting agriculture from damage by the environment. It is possible to make a gross assessment of the damage done the land by nine thousand years of agriculture. Approximately 36% of the land surface of the Earth has a desert climate, and yet 43% of the land area is desert. This difference, which amounts to 9×10^6 square kilometers, is man-made. Tillage has led to erosion. Irrigation has seeded the soil with salt. Irrigation has created vast, desolate marshlands. An additional 2×10^7 square kilometers of once productive land have now become so badly degraded that its use is marginal, at best.

CEA may be the only complete answer to this problem, the damage to the environment by agriculture. It uses but little land, and it takes nothing from the soi. When plants are grown in soil in a CEA greenhouse, obtaining all necessary water and nutrients from a drip irrigation system, voiding nothing into the environment because there are protecting membranes beneath the sand and in the air overhead, there is no degradation.

The other problem, environmental damage to agriculture, has two parts. The first part is that sector which is man-made. In areas of extreme environmental pollution, for example, plant production is difficult, if not impossible. Acid aerosols from industrial processes may make even CEA infeasible. These problems, however, may be generally self-correcting as regions of degraded surface atmospheres are cleaned up by their own populations. CEA does make it possible to have a significant amount of crop production in and near urban, industrialized areas, given an appropriate mix of atmospheric gases and sufficient amounts of solar radiation.

The second part of environmental danger to agriculture is that which results from long-term natural processes, principally changes in climate. That there is now some sort of global change of climate in progress is generally accepted. There is argument among the experts what this change may represent, with some expounding theories of global warming, partly man-made because of the "greenhouse" effect of increased levels of carbon dioxide in the upper atmosphere, while others believe that a global cooling trend is underway, the first beginnings of another ice age, perhaps. To the best of our knowledge, the preponderance of scientific belief at the moment leans toward the cooling theory. If this be correct, there will be, some time in the future, massive shifts in the areas of productive open-field agriculture. This would work to the disadvantage of some producing nations, principally the Soviet Union and Canada, as the good growing climate shifted south. This would also benefit other producing nations, as once marginally agricultural regions could bask in more temperate weather with greater amounts of sunlight. The long-term effects of such alterations are another intriguing puzzle we leave to the social scientists, except to observe that CEA would make it possible, in any such slow shift of climate, to retain some local food production in optimum environments even as growing zones became altered.

<u>In summation, then, what is the potential of controlled-environment agriculture for the world generally, and for developing countries specifically?</u>

CEA will <u>not</u> produce cheaper food. It will <u>not</u> feed the starving poor of the world, unless the food is given away or the poor obtain the economic power to buy it.

CEA <u>will</u> vastly increase production, use smaller amounts of land and water, not degrade the land, reduce crop loss due to weather and

insects, make it possible to grow the food when and where it is needed, eliminate some of the need for storage and the attendant losses in storage, eliminate much of the risk now faced by farmers, contribute components of great benefit to open-field agriculture and, in general, lead to various levels of economic and technological improvement.

We submit that, despite its higher costs, CEA can have current applications in developing countries as elsewhere; that these applications are now site-specific due to various constraints, but that as the world demand for food continues to increase, and the amount of arable land continues to shrink, it will become increasingly necessary for food to be produced in regions that are now non-productive, including desert regions. CEA will then not only be useful, it will be imperative.

* * *

(Editors' Note: Mr. Collins presented the above paper and participated in the following discussion. Mr. Hodges was out of town at the time.)

Discussion

Q. Are you familiar at all with the work that John Todd is doing with controlled environment agriculture and aquaculture, sort of a combined-together type thing?

A. Combined polyculture systems. There are a number of people who have been working with this sort of thing for some time. Usually, the systems are fairly simple involving an algal community growing in a pond fertilized by human or other waste materials, and then having a fish,like Tilapia, for example, which browse on the algae. So you have got some production in animal protein as well as plant material. We are familiar with a number of those experiments.

Q. Do you think that might have more application in something like subsistence farming? In terms of the fact that it is less energy intensive, it won't involve as much investment for the small farmer.

Q. For subsistence farming, family scale operations and that sort of thing, sure. They have been practicing this type of polyculture in Asia for generations. Particularly in places like the Philippines. You will have a little farm, and there are the chickens and pigs, and there are the people and their fish in the ponds, and you have a beautiful little cycle going. But you can't do that economically on a very large scale, and you can't do that in a place like the United States, where there are severe cultural and regulatory constraints on the produce from this type of cycle.

Q. If a developing country wanted to go to CEA as a means of subsistence, what would be the per capita cost to raise crops for a subsistence level?

A. Forget about subsistence farming in almost any conceivable application, unless the crops are grown not to feed the indigenous population but are used to supply food to a neighboring market area which is sufficiently affluent to buy them. For example, using CEA to grow winter crops in North Africa to provide the European market with off-season produce is something that would make a great deal of sense. Under those circumstances, if it was part of your question, and I'm not sure that it was, you could have smaller, family-size CEA operations. In fact we have just designed one for Puerto Rico in which there will be relatively small CEA greenhouses combined with family residences.

Q. We have a developing country that, through abuse, has exhausted its agricultural land almost completely, and we want to rehabilitate this country. But to rehabilitate, we have got to keep livestock off the land, and possibly have to reduce the agriculture production over a number of years. In the meantime, we may be spending money in that country to provide food for them. What would be a possibility of using this intensive agriculture to replace the money that we are pouring into those countries for food?

A. I would say that in site-specific applications, it could be done. If you have the water available. Again, while CEA uses less water than open-field agriculture, you still have to have water, and if you have to develop new resources for that water, it could get awfully damned expensive. You have got to have other forms of energy inputs as well; you have to have electricity, and all the rest of that. So I think you would have to take a look on a site by site basis of the specific trade-offs involved. I would imagine that, in some areas, the technique which you mentioned would be at least as cost effective if not more cost effective than just socking in there with massive amounts of money or bringing in crops that have been stored in other parts of the world.

Q. You mentioned how some crops, rice for example, cannot be grown economically in CEA, but you mentioned increased production of about 10 or 15 times over what you can get in field production. This is fantastic.

A. Well, we have grown some very good rice crops in CEA houses. What I said was, if you took the highest record yields of rice in open-field agriculture, and you multiplied those by a factor of 10 to 15 and got that out of the CEA greenhouse, it still wouldn't pay for the capital costs. Capital costs are one of the big constraints today for these facilities.

Q. Considering the amount of fossil energy required for this operation, I would like to know what kinds of problems you find utilizing solar energy.

A. Well, first of all, a greenhouse in the act of being a greenhouse is also a solar collector. Consider the winter time here in Tucson,

for example, where no day-time heating is required of CEA, and actually very little night time heating is necessary. To utilize solar energy to replace as much of the fossil fuel energy input as possible is something we have taken a look at. In fact, we have designed a greenhouse which has a fossil fuel energy input of zero. The whole thing operates on solar energy. But it would cost you 16 arms and 2 legs to actually build such a thing. I don't think anybody will ever build it as we have designed it, but it can be done. You can move air, for example, through a greenhouse, and even move it through evaporative cooling pads just by utilizing the solar thermal chimney effect.

An Argonne National Laboratory Venture In High Technology Transfer

NORMAN HILBERRY*

During the latter half of the 1950s, and extending into the 1960s, the Argonne National Laboratory carried on a technological transfer project with numerous developing countries, and some industrialized countries. Starting in December, 1954, it began the organization of its International School of Nuclear Science and Engineering (ISNSE), and accepted its first class of students in March, 1955. ISNSE sessions continued through February, 1960, when the format of the activity was radically changed. It continued into the 1960s as the International Institute of Nuclear Science and Engineering (IINSE).

A note is in order as to the background of this project. Argonne National Laboratory is the post-war institutional successor to the wartime Metallurgical Laboratory, which was set up and

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operated by the University of Chicago, first for the U.S. Office of Scientific Research and Development (OSRO), and then, as production operations loomed on the horizon, for the Manhattan District of the U.S. Army Corps of Engineers. The Metallurgical Laboratory and its sister institution, the Clinton Laboratories, near Knoxville, Tennessee, also operated under contract by the University of Chicago, was responsible for doing all things necessary to establish the processes required for the production of plutonium of the requisite weapons quality, and at production rates of military significance. The Metallurgical Laboratory was responsible for the necessary basic research in all of the concerned scientific and technological disciplines. This included all of the work on the self-sustaining nuclear chain reaction and associated nuclear reactor design activities, as well as the initial and continuing studies in chemistry, radiobiology, toxicology, metallurgy, and basic engineering. The Clinton Laboratories produced in its X-10 reactor the test quantities of plutonium required for chemical separation pilot plant studies, for the biological studies of plutonium toxicity, and for the weapons research at Los Alamos, New Mexico.

At the end of the war, it seemed clear that military applications of nuclear energy were certain to be of continuing importance, and that there was a large array of possible civilian applications that had to be explored for their potential values to the national economy, and for their possibilities in expanding the nation's scientific, medical, and technological capabilities. In consequence, the federal government continued the operation of the Metallurgical Laboratories as the Argonne National Laboratory (ANL), and continued the Clinton Laboratories as the Oak Ridge National Laboratory (ORNL). Shortly after the federal Atomic Energy Commission (AEC) was established, Argonne was designated as the U.S. center for reactor development.

The Argonne research and development program was divided fifty-fifty between basic research in nuclear and atomic physics, chemistry, biology, metallurgy, and solid state physics on the one hand, and, on the other, the various facets of reactor development, from basic reactor physics, through all phases of reactor engineering and design to continuing fuel cycle investigations in chemical and pyrometallurgical separations processes and waste management studies. Due to "cold war" pressures, culminating with the Soviet nuclear bomb explosion, the emphasis in the reactor development program was on its military responsibilities. These included the initial design and basic engineering studies for the Nautilus reactor power plant, which Westinghouse did the engineering design and construction on. This was barely out of ANL hands, when the Russian situation called for expansion of U.S. plutonium production facilities. ANL provided the initial concept analyses and basic design studies for the Savannah River reactors, and provided engineering support to duPont throughout their design and construction programs.

Despite these military commitments, the first "breeder" reactor, EBRI, was designed, built and operated. It not only "bred," but was the first reactor to produce significant quantities of electrical energy. The Laboratory's work on the "pressurized" Nautilus-type reactor was followed by its studies of boiling water reactors, culminating in the design, construction, and operation on the utility lines of Chicago's Commonwealth Edison Co. of the Experimental Boiling Water Reactor.

A research and development operation supported by public funds always carries an inescapable responsibility to assure that its technical accomplishments become actual functioning elements in that public's economy. Oak Ridge, which had specialized in reactor physics, met this responsibility by establishing what became widely known as Clinch College of Nuclear Knowledge, the name being derived from the river that supplied ORNL with its water supply. The degree of success it achieved is witnessed by the large number of business executives who were its graduates, or who later established the nuclear industry. Clinch College followed the university format in large measure.

At ANL, this responsibility was met by establishing an "on the job" program for industrial scientists and engineers. Participating industries were asked to meet two criteria in making their personnel assignments. The first was that they select for assignment individuals who had been with their corporations long enough to know their company's plans, capabilities, and consequent potentials for utilizing new technology, and also to be far enough up in the managerial hierarchy so that they would be listened to when they returned, and would not continually be worrying about the impact of their temporary absence on their position within the company. This was made necessary for, at the start, some companies hired new, young personnel who had no real grasp of their company's capabilities, and, when they reported back to their company, found themselves so far "down the ladder" that they had no influence whatsoever. Essentially lost in the managerial fringes, they soon left and took their company-provided experience with them to new employers looking for their particular skills. Their training paid off on a national basis, but not on that of the supporting company.

The second criterion was that the individual be privileged to stay two years, unless, in his judgement, his experience at the Laboratory was not going to be profitable for his company. We found early that the industrial scientist or engineer that had been in a tightly managed corporation for ten or fifteen years took up to a year to get over expecting to be told what he should be doing and should be thinking about. If his experience was to be useful to his company, however, it was essential that he be the one to decide what areas of the new technologies would be of most probable use to his concern, and that he choose the projects most likely to give him the experience needed to transfer that selected technology to his company.

During this entire period, these technological transfer activities at ANL and ORNL had to be conducted within the reigning security procedures. The attendees and temporary staff had to be "cleared," and the technologies they wished to transfer had to be declassified, or their home companies had to obtain contractual relationships that placed their work under secrecy wraps.

This was the technology transfer situation in the early 1950's, when the Executive Branch and the Congress decided that major segments of the nuclear technology should be declassified and opened up for civilian industrial participation. And it was at this point that ANL had its first experience with foreign technological transfer.

As soon as the probability that a nuclear weapon based on a uranium technology had become more than mere scientific speculation, the problems of denying supplies of uranium ore to Nazi Germany, in so far as that could be done, and of assuring adequate supplies for the Allies, had become matters of high priority. Belgian support had been necessary on both counts. Reports had it that there was a large consignment of uranium concentrated in Belgium, right in the obvious path of the German advance. Belgian authorities had been fully aware of the situation and its potential implications, and they transferred the entire inventory to the U.S. The second count concerned the closing of the Congo mines, which constituted a major uranium producing resource. In the negotiations making these resources available to the U.S., one consideration was an agreement that, if Germany were defeated, and if the nuclear energy project were successful and gave promise of useful civilian application, Belgium would be given priority status in any transfer of the civilian technology.

The Allies were victorious, the project was successful, and by the early 1950's the probability of important civilian uses became fairly obvious. This was becoming evident in such diverse fields as medicine and electric power generation. The Belgians felt that the time had come to cash-in their technology transfer chips. The U.S. Atomic Energy Commission agreed, and arrangements were made for a group of Belgian scientists and engineers to come to the U.S. for a broad survey course in all declassifiable aspects of the existing technology. Argonne had both the broad scientific and technological base desired, and also had facilities at the time that made it possible to isolate the visitors from classified operations with minimal limitation on their rightful activities, and without continually bringing to their attention the fact that they were still being shut out from many aspects of the technology.

As a result, eleven Belgian scientists and engineers showed up for nuclear science and technology indoctrination. They were all experienced individuals with thorough command of their own scientific,

technological, and managerial areas of expertise. ANL provided them with both the classroom and laboratory work they needed to bring their base of operations in the new areas up to date, and to provide the sources of declassified information they would need in establishing their own activities upon their return to Belgium.

It was shortly after this Belgian episode that President Eisenhower made his December 3, 1953, "Atoms for Peace" speech to the United Nations General Assembly. The speech promised to open up the civilian "atomic energy" technology for worldwide benefit. It also essentially promised the gift of a research reactor to any nation asking for it.

In the succeeding months, it became apparent that many countries wanted both the new, advanced technology, and the research reactor. It also became apparent that few countries had the qualified personnel capable of operating such a gift reactor, and of utilizing it effectively in their own interests. In fact, in many instances, it was questionable whether the governments involved had qualified advice as to whether or not acceptance of such a gift made national sense, particularly in view of the significant operating costs that acceptance would entail.

In view of this manpower problem, during the summer of 1954 ANL proposed to the Atomic Energy Commission that it make available the same sort of indoctrination course it had provided to the Belgians on an international basis. The initial curricular formulation and desclassification had been done, so that a formal but still adequately flexible course could be offered. In addition, the necessary "unclassified areas" required for classrooms, laboratories, and student study areas could be made available, given some time and relatively modest sums of money. Furthermore, qualified members of the ANL staff had volunteered to serve as faculty for such a school.

Time went on, as did continuing desultory discussion with Washington. Some thought went into the curriculum formation, and some planning for the necessary facility modifications, but as time passed with no governmental action, ANL activity also waned. By year's end, the proposal had practically been put in mothballs.

Then, on Christmas Eve, an incoming teletype announced approval of the proposal. It further announced that the first class of up to fifty students would arrive at Argonne early in March for a seventeen-week course, following one week of government-handled orientation in Washington. The message requested that a synopsis of the curriculum to be offered be sent back by return teletype, so that it could be cabled immediately to all U.S. Embassies.

These instructions posed problems. Curriculum plans were shaken out of their comatose state, and cast into a form that was sufficiently

definite to indicate the range of subject matter to be covered, but sufficiently vague to provide the flexibility we had already discovered would be essential. An acceptable synopsis was provided promptly (although not by return teletype!).

The facility problems were far more difficult. Classroom, office, and study space could be handled in stride, but to provide laboratory space and the requisite equipment took some doing. In particular, the only space that was available and suitable for subcritical reactor assembly experiments was a decommissioned power plant. It still had four boilers in place, with ash pits beneath, and ashes in the pits. With suitable high-pressure reclamation effort, and a scrounging of equipment from throughout the laboratory, March 1, 1955, found the facilities at least in usable shape.

I received instructions to appear in Washington for the inauguration of the International School of Nuclear Science and Engineering. President Eisenhower welcomed the group in the White House Rose Garden, signaling the event as a significant step in implementing the Atoms for Peace Program. An evening reception at Blair House for the students, and personnel from their respective embassies, completed the ISNSE inaugural. This was followed by the week of orientation, and the new student body descended upon our laboratory.

The planned curriculum anticipated rather formal lecture and laboratory work for the first ten or twelve of the seventeen weeks. This would cover the elements of reactor physics and basic reactor design, the fabrication of reactor fuel (including the basic metallurgy of uranium and of cladding) and construction materials, the reprocessing of spent fuel (including the basic chemistry involved), and, finally, the areas of reactor safety, potential health hazards, and the modes of monitoring to ensure compliance with radiation exposure standards. The final weeks were to be used for a laboratory or reactor design project. Reality developed in a somewhat different fashion. The time devoted to the lecture and laboratory work had to be extended, curtailing sharply the important project work at the end. The reasons were numerous; there were wide differences among the participating students in education and experience, in interests and objectives, and in cultural background.

There was, fortunately, a built-in mechanism for coping with the cultural problems. Some kind authority, at some point in the governmental hierarchy, ruled that the educational privileges afforded to foreign sponsors must be made available to U.S. sponsors, and to U.S. industry in particular. It was indicated that, ideally, about one fourth to one third of each class should consist of U.S. students. While this condition was in part a matter of assuring fairness to U.S. sponsors, it was also intended as a means of affording the foreign students an opportunity to understand the U.S. and its citizens by sharing in a common enterprise on an intimate, person-to-person basis.

It worked. Problems that the foreign students had, that they would not bring to us directly, they had no hesitation in discussing with their U.S. classmates, with appropriate animation. The U.S. students would then see to it that we were adequately, if not fully, advised. In some instances, this mechanism proved to be invaluable.

U.S. industry was glad to cooperate in this endeavor. Here was a unique opportunity. Obviously, if developing countries were to undertake serious programs in nuclear industry, these students would be at the forefront of such endeavors. If U.S. industry could make contact with them now on a "classmate" basis, it could aid significantly in opening foreign doors to U.S. enterprise in the future. Whether it has paid off in contracts is not clear, but the close U.S. friendships with foreign students that were hoped for were formed, and, in many instances, have endured. Equally important, however, may be the fact that equally strong and enduring friendships were formed between the students of the different participating nations. In some instances, at least, these lines of communication are still open.

While the U.S. student ameliorated the culture-rooted problems, and served well as ombudsman for the inevitable foreign student gripes, they did little to lessen the principal ISNSE difficulty, which was the wide disparity in educational training, professional experience, and objective for participation. Some of the U.S. students were mature engineers with significant professional experience, but many were recent graduates with bachelor's degrees in engineering. Neither group was highly proficient in their command of modern physics. The foreign students were in general better prepared in modern science than the U.S. group, but, even there, the educational base ranged from the equivalent of our B.S. degree with a major in physics, to some individuals with doctorates. Most of the foreign contingent had some professional experience in academia or industry, ranging from a few to as many as fifteen years. To tailor a curriculum that would keep the advanced students from boredom, without swamping the neophytes completely, constituted a very major challenge. To meet that challenge with any success, required flexibility in educational approach of high order. For numbers of the students it essentially meant the tailoring of the curriculum to meet their particular needs. With thirty nine students in the first class, and with sixty one in the second, this was not an inconsiderable task, even with the fairly high teacher-to-student ratio an operation of this kind required.

The diversity in the student objectives for participating in the ISNSE program was even greater than that in their educational preparation.

In the U.S. group, the senior members were largely from the managerial ranks. They were there to get sufficient grounding to plan an intelligent participative program for their corporations, if

such should seem to be feasible, or to handle the professional implementation of such a program if and when their corporations should wish to undertake active participation. In general, the junior group were assigned to become familiar with the technology, to be able to interpret and explain what was what when called upon by their bosses for enlightenment, and to serve as a corporate communication link with the new nuclear technological community, both at home and abroad.

The foreign contingent fell into two fairly well-defined groups, those who knew pretty well what their countries wanted to undertake in the nuclear field, and those who were there to find out whether there was anything that their nations should want to do and could reasonably hope to attain. Table I lists the countries that took part in the ISNSE program from March, 1955, to February, 1960, and in the IINSE activities from February, 1960, to September, 1962. The number of participants in each program is listed. There were forty four nations represented at ISNSE, with 424 students. The U.S. sent 100, for a total student body of 524. There were twenty-five nations represented at IINSE, with 170 students. The U.S. sent 15.

A scan of this table is illuminating. First, it should be noted that there were no participants from Great Britain or Canada. Great Britain had already established a school similar to ISNSE at their laboratory at Harwell before ISNSE was organized. Several of the ISNSE students had, in fact, first attended the Harwell school, and several others were sent to Harwell after completing the ISNSE course.

The fully-industrialized countries, such as Belgium, France, Germany, Italy, Japan, Sweden, and Switzerland, had simply been biding their time until they had a reasonable opportunity to get into the nuclear business. ISNSE appeared to provide at least a first step toward that opportunity, and they took advantage of it by, in effect, sending teams of participants to acquire as much technological detail as possible. The countries with strong industrialization plans, such as Brazil, Greece, India, Israel, Korea, Pakistan, Philippines, Spain, Taiwan, Thailand, and Turkey, took much the same approach. Their teams were perhaps not quite as well aware of just what technological details to look for as were the more advanced industrial groups, but their major objectives and motivations were the same. It was members of these groups in the first two sessions that felt the lack of sufficient time for adequate personal practice in laboratory experiments (or design projects) most keenly, and complained about it most effectively. And in both groups, the main interest centered on the nuclear reactor as an industrial power producer.

A few of the other less industrialized nations that participated had definite long-range nuclear industrialization plans, and were concerned with acquiring technological detail as the essential first

TABLE I

COUNTRY	ISNSE	IINSE	COUNTRY	ISNSE	IINSE
Afghanistan	2	-	Korea	22	4
Argentina	4	-	Mexico	3	-
Australia	2	-	Netherlands	9	3
Austria	7	4	Nigeria	-	1
Belgium	23	-	Norway	2	1
Brazil	14	19	Pakistan	21	1
Burma	7	2	Peru	3	-
Ceylon	1	-	Philippines	10	3
Chile	5	-	Portugal	3	-
Cuba	2	-	South Africa	1	6
Denmark	4	1	Southern Rhodesia	1	-
Ecuador	2	-	Spain	34	4
Egypt	8	2	Sweden	8	1
Finland	4	2	Switzerland	11	-
France	15	2	Taiwan	14	6
Germany	27	5	Thailand	15	3
Greece	16	-	Turkey	11	-
Guatemala	1	-	Uruguay	2	-
India	15	28	Venezuela	5	-
Indonesia	5	-	Vietnam	-	2
Iran	3	1	Yugoslavia	3	12
Iraq	5	-	Subtotal	424	170
Israel	9	5	U.S.A.	100	15
Italy	35	7			
Japan	30	46	Total	524	185

step toward their realization. However, they joined with the others in this group in wanting a broad assessment of the total potentials that nuclear energy applications might make available, whether in the application of artificial radioactive isotopes in medicine or agriculture, in the use of nuclear explosives in civil works, or in the use of nuclear reactors for the generation of electrical energy. For their national needs, the research uses could be more important than power production.

It was clear by the end of the second class, that something needed to be done to achieve a more uniform educational base upon which to build the technological superstructure, and, also, that the time made available to do even the promised introductory job in an acceptable fashion was far too short.

In the meantime, a new factor had come into the situation. Some U.S. universities chose to view ISNSE as a first step toward the establishment of federal universities, and they objected strongly. They maintained that education was the business of the university community, that they alone possessed the skills to do the education job effectively, that federal government competition was intolerable, and that it should withdraw from that competitive position before it took the next inevitable step and began granting degrees! At that time, none of the universities were in any way competent to present the full range of lecture, laboratory, and design work that ISNSE was giving. They lacked the experienced faculty required in the broad range of disciplines involved, and they lacked the essential specialized and expensive facilities needed for the laboratory work that gave the course its unique value. Their concerns, however, were deep, and the pressures exerted were considerable. While the nuclear technology course, as ISNSE was giving it, could be justified and successfully supported against the university pressures, it was certainly not clear that a similar argument either could or should be made for presenting a semester long pre-program at ANL, whose purpose was to provide each student with the evened-up technological base that the ISNSE curriculum needed in order to be fully effective. Moreover, by this time, two universities possessed research-sized nuclear reactors, so that they were in a position to provide the important introductory reactor experiments.

ISNSE was operated as a joint program between AEC and the International Cooperation Administration (ICA), the predecessor to the U.S. Agency for International Development (AID). AEC made the faculty and facilities available and vouched for the program, and ICA made the student funds available. ICA charged the participating nation $1,000 per student per semester as tuition. I believe that this could be paid for out of available ICA funds, and that in some instances it was so paid. Where the foreign student was sponsored by an industry abroad or at home, the tuition was paid by that industry. The travel and living expenses were paid for by the sponsor. Whether these

could be drawn from ICA funds in some cases was never clear, but our estimate of the costs to the sponsor , however funded, was about $10,000 per student per semester. The costing process was carried on under what is called in governmental circles "full cost recovery" procedures.

What it did in this case was to give ICA full authority to carry out a quaint custom they called "program evaluation." This turned out to be a psychologically rough, but operationally valuable, technique, at least as it was carried out with the ISNSE student body. ICA sent out an evaluator who met with the students, both in small groups and en masse. All phases of the operation were open for "critical discussion." These were completely uninhibited, no-holds-barred sessions. The students said what and who they liked, and why. They were at least equally emphatic about what and who they did not like, and again why.

As a result of these evaluation hearings and Argonne's own recommendations, the format of the ICA-AEC program was changed and doubled in length. Starting with the third class, and continuing through the ninth and last class, each assembled in Washington for its week of orientation. The class then split into two, one going to one of the universities with a reactor, and the other to the other so-equipped institution. There they had their deficiences in technological background filled in, and their introduction to nuclear engineering presented. At the end of the seventeen-week period, they went on a three week tour of some of the nation's nuclear facilities, mines, laboratories, and industrial installations. They then went to Argonne for seventeen weeks. The first segment at ANL was a period of intensive lecture and laboratory work, now assuming a general competence on the part of all of the students in each technological area, and thus concentrating the ANL presentations on the nuclear extensions into those areas. Previous experience indicated that the weakest point in the foreign student's training lay in his laboratory skills, since, in many instances, much of his work in foreign institutions appeared to be done for him by professional technicians, with the student's own contributions being confined to data manipulation at the end of the equipment. Thus, they frequently lacked both manipulative "know-how" and operational judgement. At ANL, these were made important facets of the course. Everyone got his hands dirty. The latter part of the time at ANL was devoted to either a laboratory research project, or to a design problem which would give the students an opportunity to test the extent of their acquired information base and their own capability for using it in a practical application. At the end of the ANL period, it was off to Washington for a final go-around, and then home.

The student reactions to this program, as might be imagined, ranged widely. The views of the orientation week in Washington varied from a welcome glimpse of U.S. life and customs, to a bitter belief that the

students were being forced to spend their money to be bombarded by U.S. propaganda. The latter feeling was a minority response in all cases, but the minority was larger in the later classes.

The student evaluation of the university stay expressed something less than euphoria. The acceptance into the community and the insight this provided into U.S. life and its customs was generally assessed as invaluable. The course work fared less well. For one thing, the reactor at one institution broke down and was decommissioned just before the first group of students arrived. This was a serious blow to the institution's program. The reactor experiments at the other institution constituted the highlight of its course, as the lectures in reactor theory did at the other school. But other than these highlights, there was general discontent. The students felt that, in general, the faculty considered the courses they were presenting to them to be extra-money incidentals, examples of what they called the U.S. "short course" disease. Their second complaint was that, in general, the faculty had no actual experience with the matters they were presenting. They were unable to tie the presented text to its actual use in real world technological practice. The fact that very few of the involved faculty had ever had any "field experience" constituted a serious handicap as far as these students were concerned.

The tour phase of the program was fine in theory, but frustrating in practice. Although the time available for the tour was tightly limited, some federal rule prohibited fast air travel, and required that all transportation be by railroad or bus. The result was that many days were spent in trains, while the inspection visits had to be raced through in a few hours. In one major laboratory, the students were rushed through in four hours, getting only passing glimpses of its unique and internationally famous facilities. Then back to the train windows! A visit to a uranium mine was described by one student: "We drove into a hole on one side, through a tunnel, out a hole on the other side, and back to the train." Other students said that description was slightly exaggerated, but only slightly. The industrial hosts who had obviously taken real pains to give a top flight demonstration of the state of the industrial technology were frustrated by the rush-through pace. The pessimists among the students considered the tour a total waste of time and money. The optimists felt that they got a marginal, if totally non-nuclear, return from the ever-changing view out of their train windows. The slightly greater coach airfare cost over the train ticket cost would have gladly been paid by most, if not all, of the student sponsors. This would have given the time distribution a justifiable balance, with the students gaining an adequate view of the nation from coast to coast while still being able to feel that their primary nuclear interests were, in fact, receiving top consideration.

Back at ANL, for the final seventeen weeks, things moved much more smoothly under the expanded time scale. With the basics having

been covered at the universities, it was possible for ANL to tailor the student study programs in the first period, and their laboratory projects or design problems in the second, so that they almost satisfied precise individual desires. This was never fully possible, but it could be accomplished closely enough that there were few student complaints on that score. Nor were there complaints on the professional competence of the faculty or the willingness of the laboratory staff outside the school domain to give counsel on matters of professional student concern. We did have gripes on the expository skills of some faculty, and upon the apparent lack of preparation others gave to their presentations. In general, however, student satisfaction with their accomplishments at ANL, as estimated from the ICA evaluations, was high.

Both from the viewpoint of the participating nations and from that of the U.S., the evidence is that the ISNSE project was a success. Table II gives the numbers of students per class that ISNSE served during its relatively short operating period.

TABLE II

DISTRIBUTION OF STUDENTS BY SESSION

SESSION	# FOREIGN STUDENTS	# U.S. STUDENTS	# TOTAL
0	11	0	11
1	30	9	39
2	39	22	61
3	46	14	60
4	47	13	60
5	53	14	67
6	55	11	66
7	55	5	60
8	50	7	57
9	38	5	43
Total	424	100	524

This student body not only provided significant leadership strength to foreign nuclear energy programs but also provided some of the leading U.S. nuclear industrial corporations with members of their top management staff. When Belgium established its Nuclear Center at Mol, the

the director, the deputy manager, and associate director, the director of international affairs, and the heads of several of the Center's departments were all ISNSE "graduates." The Scientific Counselor for the Belgian Embassy in Washington was another of the Belgian participants. Four other Belgian students moved into top spots in EURATOM, the six-nation European nuclear energy agency. Others of the Belgian group were drafted for top management spots in Belgian industry. Several also assumed positions as university faculty members, either as professors or lecturers on a full or part-time basis. As one of the Belgian group commented some ten years after his ANL residence, "The Argonne experience moved all of our group into positions of managerial authority that, in the normal course of advancement, would not have been open to us for another twenty or more years. Obviously, we have a very warm spot in our hearts for Argonne."

As another example, one of the two Australian students is one of the top managers of the Australian Nuclear Energy Center, and the other a top official in the government's energy department. In another case, one of the Pakistani students went to the International Atomic Energy Agency, serving for many years in its reactor section. He has now returned to Pakistan as head of the Pakistani Atomic Energy Agency.

These are but random samples that have come to my attention. I know that similar roles are being filled by ISNSE students in Latin America, in Africa, in Europe, and in Southeast Asia and India. A new survey of the current whereabouts of our former students would be both interesting and enlightening.

The two principal external conditions that limited the ISNSE effectiveness significantly were the inescapable structures imposed by the need to work within established governmental rules and regulations, whether truly applicable to the situation in hand or not, a constraint that is always imposed on activities operating with federal contract funds, and the equally inescapable headaches that attend cooperative endeavors, particularly those where some of the cooperators are universities, and others are not.

In the ISNSE case, there was evidence both of impact of the basic administrative rules malady itself, and of the effects of ministrations by below-standard administrative practitioners.

For a few students, their problems started early. The U.S. Embassies handling their applications refused to provide any indication as to their chances for having their applications accepted, so no sort of responsible planning was possible. Then, they were suddenly notified that they had been accepted, that their transportation had been arranged, and that they must be at the airport for departure to the U.S. in something less than 48 hours; 48 hours to prepare for a four to five month assignment abroad! It was never clear whether these instances of apparently cavalier treatment were due to ineptness at the Embassy level, to a breakdown in the diplomatic communication system,

or to an operating failure in the ICA organization in Washington. Fortunately, student complaints on this particular score vanished as the program continued, although the application-acceptance-"matriculation" sequence was never totally without its rough spots.

When the students arrived in Washington, it was not a matter of a few with complaints. They all complained with varying degrees of intensity. The first act of ICA upon a participant's arrival was to confiscate his return ticket and place it in escrow in Washington, pending completion of the assignment. The possibility of urgent need to return home because of family emergency on holidays or weekends, when the ICA offices would be closed, were dismissed as unlikely, and the practice justified as being a standard governmental regulation governing all such projects. It was accepted grudgingly and remained a continuing irritation for many of the participants. Another instance of this same attitude, already discussed, was the drastic waste of "visiting" time on the tour by insisting on train and bus travel, apparently to save the dollar difference between coach air fare and the costs for train and bus transportation.

One more complaint of similar nature was the adamant regulation against the possession or lease of an automobile by any participant. This constituted a major limitation on a participant's ability to take full advantage of his professional opportunities at ANL. The Argonne site is some twenty five miles from possible participant housing on the University of Chicago campus, and ten or more miles from possible housing in the suburbs nearest to it. Since there was no public transportation to the site from any location, it was necessary for the laboratory to provide both housing and bus service for the participants. The bus only ran on the five official laboratory work days. Thus, although the laboratory was open and the school facilities available on weekends, there was no way for the students to make use of them. What happened, of course, was that some of the most ambitious of the students discovered the art of "thumbing" a ride, and got back and forth that way when the bus was not operating. For a while, that meant hitch-hiking clear across Chicago's South Side, which, even in those days, could be an adventurous proceeding.

The other major problem area with which the ISNSE program had to deal with, was that of its interaction with the cooperating universities. The decision to break the nuclear technology transfer program into the two segments was the product of university pressure on the government to cease and desist from its setting-up of a competing education institution. The universities maintained that they were the nation's established and properly-qualified mechanisms for providing the full range of technological education, and were competent to provide that education in this specific case also. The university fear was that, if the school were to become a firmly-established institution, it would inevitably move to grant degrees. If that goal were to be achieved, it was easy to visualize a host of federal universities springing up in competition with the established state and private institutions. It

was also easy to imagine that such institutions, with direct federal support, might well find themselves in a much more favorable budget situation than the established state and private universities.

The ANL administration, being comprised of university people, recognized the validity of the university community's concern. It was also keenly aware of the need to fill-in and even-up the technological background of the ISNSE students before an effective job in the transfer of nuclear technology could be accomplished. ANL was not ideally equipped to do the necessary technological broadening and updating, although it could do so if necessary. If the universities could do it, so much the better, for then ISNSE could avoid the purely educational requirements of the program and concentrate on the technological transfer activities, for which its staff were uniquely qualified. Since the universities, for obvious reasons, did not press a claim to the specialized technological transfer phase of the program, the Laboratory supported the divided program approach and it was put into effect with the third class. The student complaints were immediate and grew stronger with successive sessions.

As session succeeded session, student preparation and subject interest displayed the shift in participating nation needs. In the first session, the need had been for relatively senior (in terms of modern technological know-how and judgement) types who, upon return, could advise on national policy with respect to nuclear technology, and take an active part in the administration of whatever national program might be implemented. As national plans progressed, however, the needs shifted to the development of the specialists in the various phases of nuclear technology envisaged as important in the national nuclear programs. This meant that the students were generally better prepared for undertaking their new, more specialized assignments, were much less concerned with the broad technological perspective, and wanted to put in every possible moment of their stay at the ANL technological frontier. The insistent cry was for more time at Argonne, and less at the universities.

By the fourth year, the student complaints were insistent, and the trump they finally played was the fact that, in many cases, the class one and class two participants organized and made available, back in their own countries, introductory courses that were fully as good academically, that were better adapted to their own student's needs, and that were very much cheaper than the university courses given in the U.S. This argument made its point with the ICA. ISNSE was phased out with the nineth session and the International Institute was phased in.

The Institute program shifted back in its operating philosophy to something close to the early on-the-job technological transfer technique. Special seminars were arranged for small groups as they were needed, but the backbone of the program was the assignment of each individual to a project that gave him actual practical experience in

that phase of the technology in which it was planned, that he would have an active role when returning to home base. To ensure that the Argonne experience would be adequate to assure command of the technological field assigned, the time limits for work at the Laboratory were drastically altered, with the minimum for a participant in any field being no less than one year, and extending for some assigned to the more complex areas to two years or more.

The ISNSE-IINSE case dealt with a highly advanced rather than with an "intermediate" technology. In either case, however, the transfer problem from one nation to another is, at its root, a transfer between persons. Obviously, some facets of the transfer technique will differ in the two cases, but I believe that many others are people-dependent and not technology-dependent. It is for this latter set that I would hope that the Argonne experience might provide some guidelines for future programs in the transfer of technology to developing countries.

* * *

Discussion

Q. You mentioned the existence of two quite different audiences as participants in the ISNSE-IINSE program. This point of differing audiences within technological transfer projects has come up in previous seminars. Was there some common ground that made it possible to serve both groups effectively?

A. The answer is yes, there was. When categorized in terms of the reasons they had been sent to the school by the various participating nations, the students fell into two clearly-distinguishable classes. Those from the industrialized or rapidly industrializing countries were there to obtain the specific items of technical information and of application experience needed to introduce nuclear technology into their own technological complexes as quickly and with as little lost motion as possible. Each national felt sure that an innovative technological advance of this magnitude was bound to have major industrial impacts. I suspect that each also felt that only from a firm industrial nuclear base would it be possible to assess the full military significance of nuclear weapons.

The students from the as yet non-industrialized countries, on the other hand, were only modestly interested in immediate industrial potentials. They were not at all interested in the industrial production of power producing reactors or other nuclear devices. They were concerned with being able to evaluate the usefulness of such systems and mechanisms in their established economies, to assess effectively the comparative technological

merits of competitive bids to supply nuclear equipment and services that might be ordered, and to train the personnel needed to manage and operate any nuclear facilities that might be judged by their nations to be both useful and economically justifiable. The object of their immediate concern was the question as to whether or not their respective nations should acquire a research reactor. Thus, they were fully as interested in what nuclear technology could mean in its impact on such activities as agriculture and medicine as they were on the technology of the reactor itself.

While these ultimate objectives were disparate, the means of satisfying them at the primary level were not. The basic principles of nuclear technology were the same whether they were to be applied to industrial design and construction or to safe and effective operation and use of nuclear systems. Since time permitted no more than the presentation of the basics, this meant that a single comprehensive curriculum satisfied the needs of both. The students were left to develop their own individual assessments of national needs and the options open to them to fill those needs. The faculty advised, but left the initiative with the student.

Similarly, both groups were anxious to know what the range of applications tested had been, and what were the results. For the industrial group, this gave a base for estimating a demand for equipment and services; for the non-industrials, it provided a view of the benefits that might attend the adoption of various elements of nuclear technology in their own economies. Again, the faculty simply presented what had been accomplished. It was left up to the students to assess the usefulness of those accomplishments in terms of their own national situations. The faculty advised on ways to implement their suggested plans, but again, it did not advise on what the plans should be.

Most of the industrial group of nations moved into some facet of the nuclear industry, mostly into the power reactor design, construction, and use, and into the associated fuel cycle activities. In these cases, the students moved into managerial and lead technical positions. A significant number were given professorial assignments of one kind or another in the universities and technical institutes to begin educating students in the engineering aspects of the nuclear industry. These would shortly be needed to supply the continuing flow of highly trained engineering manpower that a thriving nuclear industry requires. In both cases, however, the Argonne experience played a continuing and significant role in determining the nature and the course of the national nuclear programs that evolved.

In the non-industrial cases, the impact of the Argonne assignment varied widely. In one instance, the student returned to a situation in which his only advice could be to essentially ignore all

things nuclear, certainly for the immediate future. He himself went into private business, kept himself at least somewhat up to date on nuclear technology and its progress, and served as that government's "advisor" on nuclear matters on a continuing basis. In other instances, research centers were established with a research reactor in order to support and strengthen on-going programs in agricultural research and medical practice. In numbers of cases, the students returned to professorial positions in their nation's universities, serving as national advisors on nuclear affairs and representing their nations at international nuclear meetings and on international nuclear boards from the base of their university positions. Here again, the Argonne training carried over not only influencing the nuclear scene within the nations, but it had impact on the international scene because of this national use of ISNSE-trained personnel on their official international delegations.

Q. Do you think it is wise to aid in the development of nuclear energy in other countries in view of the fact that India has used such assistance to build nuclear weapons?

A. As far as what a nation does about making nuclear weapons is concerned, I doubt if it makes much difference what we think or what we do about aiding them in establishing peaceful uses of nuclear energy within their economies. If the U.S. refuses to provide such aid, others will be glad to do so, for this tends to close the door to our influence and to open the door to theirs. If the "others" are "friendly competitors," this could be but a modest loss; if the "others" happen to be "ideological opponents," this could constitute a major diplomatic defeat.

This question of effective safeguards for the nuclear industry is complex, and would take more time than we have now to cover in any sort of proper detail. It is true that plutonium purloined from a nuclear power production fuel cycle could be used to produce a nuclear weapon of sorts. The purloining of militarily-significant quantities of plutonium would be difficult to conceal, and the weapons produced would have important faults. Given sufficient determination, a nation could no doubt evade all control inspection procedures and eventually divert some plutonium and construct a few weapons that would work after a fashion. I find it difficult to envision any way in which a terrorist or gangster group could do so successfully.

It should be remembered that no nation, industrialized or well on its way to industrialization, needs either our aid or that of anyone else to provide itself with weapons-grade plutonium. If it has the well trained scientists and engineers that its industrial status would indicate, if it has access to uranium ore, which it could almost certainly arrange, and if it has a desire to possess

nuclear weapons that is so overwhelming that is willing to sacrifice the necessary slice of its gross productivity for the time span required to achieve its end, any nation so endowed can produce weapons-grade plutonium just as the rest of the "nuclear club" nations have done. While the advanced industrial nations would make the task difficult if they knew what was being done, it is doubtful that they could stop it.

A program of commercial cooperation in nuclear industrial areas with the non-nuclear club nations, if carried on under suitable contractural arrangements and proper implementing inspection procedures, could be a much more effective safeguard measure than would any attempt to exclude these nations from participating in all aspects of nuclear applications.

Q. What about the nuclear fuel reprocessing plants that Pakistan is buying from France?

A. The plants for reprocessing the nuclear fuel that has been irradiated in a nuclear reactor are the places that are most vulnerable to a diversion of plutonium of all operations in the entire nuclear fuel cycle. It is here that the principal safeguard hazard exists. However, the comments on the diversion of plutonium made in answer to the previous question were made precisely with this reprocessing situation in mind. The answer is, therefore, that while reprocessing facilities constitute the facet of the fuel cycle most susceptible to diversionary activities, proper inspections and process monitoring procedures, combined with really supportive contractual arrangements, should provide as much, if not actually more, international security than would attempts on our part to exclude the nuclear have-nots from participation in those nuclear activities that we view as potential modes of proliferating nuclear weapons. They may have such intent or they may not. They are almost certain to resent any attempts at exclusion and are likely to proceed on their own with whatever help they can get from whatever source. It would be inane for us to assume that the nuclear have-nots are financially too poor and industrially too incompetent to achieve the same objectives that we have accomplished. All they require is a desire intense enough to sustain the economic sacrifice required for the achievement.

Q. Is it possible to establish an inspection system which would guarantee that no plutonium was being diverted to weapons use?

A. Guarantee? Probably not, the genius of man for evasion being what it is. However, a high degree of assurance is, I believe, achievable. As already noted, the vulnerable point in the fuel cycle lies in the spent fuel reprocessing and the fuel fabrication plants. The other points in the fuel cycle are much more secure because they are much more readily monitorable and because the

hazards to the diverters in retrieving the purloined plutonium are very much greater. If the fuel reprocessing and fabrication plants were to be located on a single site, if adequate process control records were to be kept, if a tight, "from-the-top-down" management auditing system were to be carried on, and if an effective, independent monitoring program were to be established and maintained, the diversion of plutonium would be so difficult and the danger of exposure so great that it would not be worth the effort required. We tried out this approach with the operation of our research reactor at Argonne with the International Atomic Energy Agency doing the independent monitoring on a spot check rather than on a continuous basis. We were convinced that, even so, it would be extremely difficult to defeat the safeguard that this somewhat limited inspection system provided.

Q. Did you run into any cases of the "brain drain" problem in your program?

A. Yes, but fortunately the cases were few. I can only remember three or four. We were fortunate in that most of the foreign students assigned to us were so assigned with very definite purposes in mind. That meant that most already had jobs at home which could use nuclear broadening or were sent to be trained to fill planned positions for which no qualified personnel were available. As a result, we escaped the vicious circle situation that so often occurs with students from the developing countries. The countries are not developed, in significant measure, because of a lack of trained personnel. So students are sent for training, but with no specific goal in mind. They often return to find that there is no opportunity to put their training to use at home. So they leave, hindering the country's development, and taking away the cadre of trained personnel needed for its development. In our case, the precise purposes behind the student assignments to the program avoided this endemic difficulty.

On the Introduction of Modern Agricultural Technology in a Developing Country

A. WAYNE WYMORE*

This paper reports one approach to the introduction of modern technology into developing countries. The approach is very general, and it can be applied in almost any technological area, but the example discussed below is in the area of agriculture.

The problem that will be considered here surfaced because of the belief, apparently widely held among scientists and other intellectuals interested in Central America, that something on the order of 85 to 90 percent of the food consumed in Central America is produced by small farmers tilling an area of land less than ten hectares. The larger farmers are presumably in the business of producing very little food for local consumption in Central America itself. As the population of Central America increases, therefore, it will be necessary to increase the production of these smaller farmers, assuming that the ratio of production for consumption of food in Central America continues.

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It was with this basic motivation that the Centro Agronomico Tropical de Investigación y Enseñanza (CATIE), an international research center operated by the Interamerican Institute of Agricultural Sciences of the Organization of American States at Turrialba, Costa Rica, began to study the problem of increasing the production of small farmers in Latin America. They began with the standard Green Revolution-type techniques; that is, they developed, or began to try to develop, better varieties of corn and beans, and other staples of the Latin American diet, that were more resistant to disease, produced larger and more nutritious crops, and were certainly more profitable products. But these newer varieties inevitably required fertilizer, herbicides, insecticides, and so forth, and tillage practices that were unknown or impractical in the Latin American tropics.

The story was told, probably apocryphal, that a new variety of bean had been developed by CATIE which was more highly nutritious, had a great deal more protein in it, was more resistant to disease, had many other desirable characteristics, and so on, but when it was introduced to the farmer, the farmer took one look at it and said, "Oh, but Señor, these beans are red! My family only eats black beans," and ruefully tossed them over his shoulder. Whether this story is true or not, it does indicate that the problem is more complex for Latin American farmers than the corresponding problem in the United States. The U.S. farmer is reasonably well educated and is a businessman. If he can be shown that, by changing his practices, he can make more money, then he is much more inclined to accept the changes. The Latin American farmer is much more involved personally, emotionally, and in many other ways in his farm system. Therefore, his problem is much more complicated than the problems of the farmers in the United States. This is somewhat of an oversimplification, but these are the kinds of problems that the people at CATIE were experiencing.

The small farmer and the problems of the small farmer are terribly complex. Because of the diversity of resource endowments, methods, skills, beliefs, and preferences, the numbers of separate and composite activities engaged in, the number of effective constraints impinging on these activities, the crucial temporal interdependencies among activities, the poor records and information base for decision-making, the number of attributes of the performance of the farm which enters the farmer's utility function, and last, but by no means least, the inevitable lack of certainty in nearly all facets of production, marketing, and life of the small farmer, tend to make this problem extremely complex.

This complexity implies that the essence of the small farmer's problem cannot be captured adequately in simple soluble models or by naive approaches to his problem.

On the basis of the realization of these facts of life, the personnel at CATIE began to understand that their problem was not a

problem in agronomy but a "systems problem" and that perhaps it should be approached from the "systems" point of view. Through an ex-student of mine who was involved in agricultural research in Latin America, the people at CATIE and I got together while I was on sabbatical leave from the University of Arizona. At CATIE I began to try to approach the problem of increasing the food production in Latin America by the application of systems engineering methodology.

The rest of this paper is divided into two parts: the first is a brief description of the methodology that was used in the context of increasing agricultural production of small farmers, and the second is an example of the application of this methodology to the problem in a limited context.

The basic conclusion that one should draw from all this is that, to choose a piece of technology from the United States, and to look for a place in developing countries in which to apply this piece of technology, has to be a woeful mistake. This mistake has been recognized by those who have begun to talk about "intermediate" technology and "appropriate" technology, and yet it is precisely the definition of "intermediate" or "appropriate" that is the real problem in almost all of the developing countries. If, instead of looking for problems where we might be able to peddle some technology, we apply systems engineering methodology to a <u>given</u> problem, then we are forced to state the problem as precisely yet as comprehensively as we possibly can and design the solution system that will be implemented in appropriate technology. Appropriate, in <u>this</u> case, means that, of all the solutions we can visualize or compute or dream up in any fashion whatsoever, we choose the one which maximizes an order or an index that represents a comprehensive statement of the various trade-offs which are involved within the problem at hand. It would seem that the worst thing that one could do is to impose upon a very complex, man/machine social problem a given hardware solution that only serves to "solve" a small part of the problem. On occasion, a simple mechanical improvement has been reported to have almost magical effects; it seems to increase a simple productivity measure of one kind or another, or to be somewhat labor saving. My feeling is that, at best, these can only amount to Band-Aids on the problem, and, at worst, can do more harm than good by making the people in developing countries look upon us as people that provide superficial solutions to complex problems.

Therefore, the basic recommendation out of all this is that first, or at first, we should only export systems engineering methodology once we have really found out what the problem is, and then we can export whatever technology seems to be appropriate within that comprehensive problem statement.

We are now going to discuss a theory of systems, and a theory of the design of systems. These theories are highly mathematical, but the discussion will be intuitive and heuristic rather than mathematical. Limitations of space, however, dictate that the discussion be somewhat

sketchy, and the discussion may still appear to be somewhat abstract. A complete exposition is found in the book, Systems Engineering Methodology for Interdisciplinary Teams.*

To design a system is to develop a model from which a real system can be built or developed, or deployed. When we are speaking of systems such as agricultural production systems, it is not so much a question of building the system as it is in organizing or deploying or developing the system.

To analyze a system is to develop a model of a system that already exists in order to make relatively small changes in the system. Computer simulations that have been identified with systems analysis can be considered as such models.

We see that both the design of systems and the analysis of systems involve models and modeling; therefore, selection of a class of models is very important because the class of models chosen will determine the power of our activities as systems engineers. We want to choose the most powerful and most general class of models possible.

To model is to choose a member of a class of models previously defined. For example, to calculate a statistical linear regression is an act of modeling because it can be thought of as choosing a model from the class of models of the form $Y = A \cdot X + B$, where each model is characterized by a value for the parameters A and B. The choice is made by computing A and B according to the usual equations of statistics.

It is a fact that, with the class of models to be discussed, we can model any phenomenon at any level of detail with any precision of prediction, if only we are given sufficient resources of time, money, computers, and so forth. Therefore, the problem of modeling is not "Can we model this phenomenon?" but, "How can we limit our model of this phenomenon and still obtain necessary information?"

If we are going to take the point of view from which we can see the human components of the system, and if we have to model in order to design or analyze a system, then we have to be able to model human behavior. We do not need to model the whole range of human behavior; we have to be able to model the behavior of men and women as components of the system, or as beneficiaries of the system, where their behavior is constrained within the system or by the system. Therefore, in spite of the fact that little is known scientifically about human behavior, we can develop models useful for systems engineering.

One engineer working alone can neither design nor analyze a large-scale, complex, man/machine system. There are too many aspects and too

*by A. Wayne Wymore. New York: John Wiley and Sons, 1976.

much work. One man alone cannot handle it. If we want to consider human components and beneficiaries of the system, then we have to consider psychological, sociological, economic, and other aspects, as well as the technical aspects themselves. Therefore, in order to design a system for a small farmer, it is possible that we would need a sociologist, a psychologist, an economist, etc., as well as representatives of the classical disciplines of agriculture, as members of our interdisciplinary team to attack the problem.

If we have a large interdisciplinary team, then we will need a very rigorous methodology in order that all members of the team know what is happening. If we do not adopt such a methodology, the result is confusion.

If we have a team of which the members represent different disciplines, then the team will have to have a common language in order to communicate. The methodology adopted ought to provide the members of the team with a language through which the team can discuss precisely system phenomena. Each discipline has its own jargon, and if each team member uses his own jargon, the result is lack of communication.

Finally, the team has to know how to state the problem of the design or analysis of the system comprehensively yet precisely without disastrous oversimplification. The methodology must provide organization and guidance to the interdisciplinary team throughout the development of the design solution.

Perhaps most important of all, a methodology must be employed in order to guide the documentation of the problem statement and its solution, because we must realize that these problems are never solved. We can only begin the evolution of the problem solution. We must see that the problem begins to evolve just as our own technological industries have evolved from Model T's, through Model A's, to modern cars, and so on. These things do not happen overnight; they must evolve through time. The only way that we can make sure that the next generation of solutions is an improvement over the last one is to have adequate documentation of the last solution, and of the problem statement exercise, in a form that allows us to discover how improvements can be made. This is an extremely important role that formal methodology must play: to provide the appropriate framework for documentation.

The methodology that we are going to discuss, called the tricotyledon theory of system design, accomplishes all these objectives: (1) It is very rigorous, based on a highly mathematical theory of systems. (2) It provides a language by means of which the members can communicate. (3) It provides a logical structure within which the problem of design or analysis of a system can be stated as comprehensively yet as precisely as resources of the team will allow. (4) It provides a logical structure within which the problem of the design, and the design itself, can be documented to provide the basis for future evolution, progress, and improvement.

Let us begin our discussion of this methodology with the development of the language of systems. It is first necessary to give a definition of the concept of system. There are many extant definitions, all of them sufficient for special purposes, but almost none of them sufficiently precise for our purposes. An intuitive notion of a system is that of a black box which has inputs and outputs; information about what is going on inside the box is called a state. An algorithm for a formal definition of a system is given in the following steps:

1. Give the system a name.
2. Define the time scale of the system.
3. Define all the inputs of the system and differentiate the various kinds of inputs.
4. Define all the states of the system.
5. Define the state transitions of the system; that is, given the present state of the system, and given the inputs from the present time to time T in the future, we must be able to deduce the state of the system at time T from the state transitions as defined in this step.

The set of all possible descriptions in the form given above is the set of all models of systems that we are going to use. We will say that a system is one of these descriptions. Thus, we will rarely find it necessary to differentiate between a "real" system and a model of a system. When we want to differentiate, we will speak of the "real" system and the model of the system.

There are many useful manipulations of the system concept which we could discuss, but for the purposes of systems engineering the most important manipulation of models of systems is to couple them. This manipulation is important because it permits us to develop very complicated models from relatively simple models. In a very complicated system, such as the system for agricultural production, it is sometimes easy to identify relatively simple components, to model them, and then to identify the input/output relations between the components. For example, in order to achieve a model for the design of a farm, we might take models of the animal components, plant components, water components, and so on, and define precisely their relationships, in order to arrive at a model of the overall system.

Based on such a very general concept of system, we arrive at the tricotyledon theory of system design. In order to state a design or analysis problem comprehensively yet precisely without disastrous oversimplification, we must accomplish the following algorithm:

1. Give the problem a name.
2. Define an input/output specification.
3. Define the technology available to construct, through coupling recipes, the system to solve the problem.
4. Define an ordering over the input/output cotyledon; that is, define an algorithm such that, given any pair of

systems, each of which satisfy the input/output specifications, one is able to decide whether we prefer one sytem to the other from the point of view of the input/output performance of the systems. The input/output cotyledon is the set of all systems that satisfy the input/output specification defined in step two above. We want to be able to compare any two systems in the input/output cotyledon with respect to the manner in which each of the systems manages the input to produce the output.

5. Define an ordering over the technology cotyledon; that is, define an algorithm such that, given any pair of systems in the technology cotyledon, we are able to decide whether we prefer one system to the other from the point of view of the use of resources. The technology cotyledon is the set of systems that are buildable in the technology defined in step three above. We want to be able to compare any two systems with respect to the use of resources. Which of the systems represents the greatest use of resources? This is the question that must be answered.
6. Define an ordering of the feasibility cotyledon. The feasibility cotyledon is the set of all systems that both satisfy the input/output specifications and are buildable in the technology. This ordering has to be a trade-off between the ordering over the input/output cotyledon representing input/output performance and the ordering over the technology cotyledon representing utilization of resources.
7. Define a plan, another algorithm, by means of which the real system will be tested.

In our context, a merit ordering is an algorithm by means of which we are able to compare two systems and decide which of the two is preferable. The merit ordering is really at the foundation of the tricotyledon theory of systems design because it is the development of these merit orderings for which the rest of the structure exists. And it is here that all the value judgments of the client of the systems engineering team must and will be incorporated. According to the algorithm given above for the statement of a problem of systems design, we need three merit orderings over three sets of systems: the input/output cotyledon, the technology cotyledon, and the feasibility cotyledon.

There are many methods for developing an algorithm defining an ordering as required. We are going to discuss one method and define a merit ordering over the input/output cotyledon of an input/output specification, where the input/output specification is a much simplified one for a small farmer.

Let us suppose we are trying to design a system for a small farmer who is our client. It is possible that we may have to assume that our farmer is more articulate than usual. We will not worry about that just now. Let us suppose that the input/output specification x specifies as output in any point in time, quantity of corn, quantity of beans, and

the gross income, among other quantities and qualities. In the case of agricultural production systems, we are interested in comparing two proposed systems with respect to the manner in which each system manages the input of rain, sun, soil, and so forth, necessary to produce corn, beans, etc. The first step in the development of a merit ordering is to discover all the criteria with respect to which the farmer would want to judge any proposal. For the sake of our example, in order to keep things simple, let us suppose that the farmer agrees to accept three criteria only: the annual expected quantity of corn, the annual expected quantity of beans, and the annual expected gross income. These criteria ought to be derived solely on the aspects of input/output, and ought to have nothing to do with methods for constructing the systems solutions. Remember that we are defining an ordering over the input/output cotyledon. Given any system Z that satisfies the input/output specification x, let us compute three expected values: the annual expected quantity of corn, the annual expected quantity of beans, and the annual expected gross income. In order to compute these quantities, we would need a probability distribution over the set of input trajectories including rainfall, irrigation, and so forth. The symbol of merit for the system Z is a vector of the three values which we have just computed.

The next step is to establish a baseline system Z_r. This system can be the present system of the farmer. We would need the symbol of merit of this system; let us say the symbol of merit of the farmer's present system is r(1), r(2), and r(3). Now we must ask the farmer to assign importance weights to each criteria. For example, we might ask him to play the following game: to suppose that he has 1,000 colones (or pesos) and then to ask himself how much money he would assign to each criterion as a prize for improving his system with respect to that criterion. He wants to motivate us to employ our design efforts in such a way that we put the most effort on those aspects of his system that he feels is most in the need of improvement. We will assume that we have obtained importance weightings by some method. Let w(1), w(2), and w(3) be the weights of importance assigned to the criteria of corn, beans, and gross income, respectively, so that the sum of the weights is one.

Let us suppose, given a system Z, we are going to evaluate the system with respect to its input/output performance as follows: we want to compare the system Z with the baseline system Z_r in order to see how much improvement over the system Z_r is represented by the system Z. We will compare Z and Z_r with respect to each criterion. If Z and Z_r are the same with respect to a criterion, then we will assume that Z and Z_r are awarded half of the importance weighting assigned to that criterion. If Z is better than Z_r with respect to a criterion, then Z will receive more than half of the importance weighting assigned to that criterion, and Z_r will receive less than half, and so forth. But how much more and how much less?

Now, the basic problem that we face is exhibited geometrically in Figure 1, in the case of the criterion of the expected annual production of corn. We want an S-shaped curve, as pictured there, that will tell us

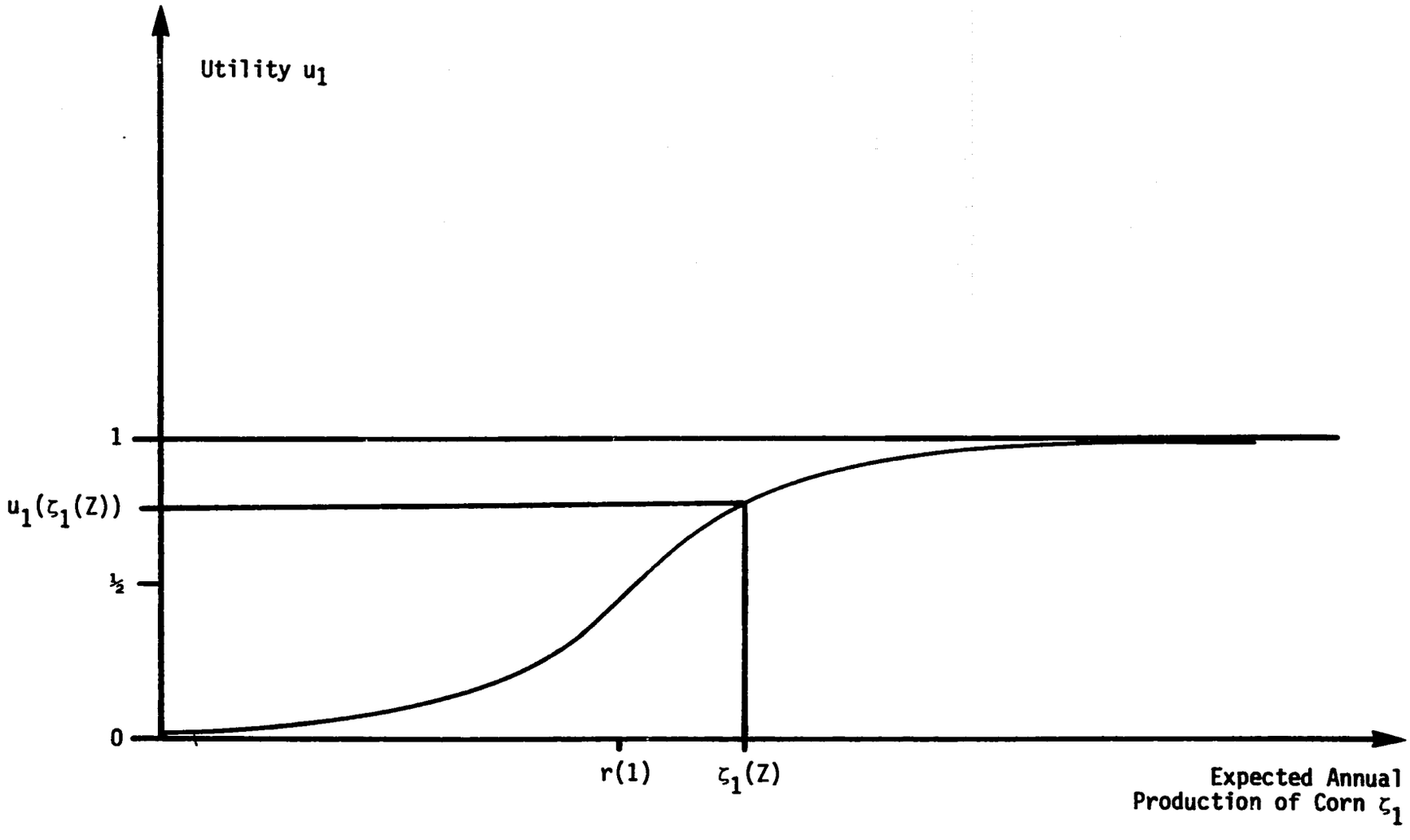
Utility u_1
1
$u_1(\zeta_1(Z))$
½
0
r(1)
$\zeta_1(Z)$
Expected Annual
Production of Corn ζ_1

FIGURE 1

the proportion, $u(\zeta_1 (Z))$, of the importance weighting $w(1)$ assigned to the production of corn that ought to be awarded to the system Z for the expected annual production of corn $\zeta_1 (Z)$. The curve ought to have the value one-half when $\zeta_1 (Z) = r(1)$, the baseline value for the production of corn. An equation of such a curve is

$$
\begin{aligned}
u_1 (x) &= 0 \quad \text{if } 0 \leq x \leq -\frac{1}{2p(1)} + r(1); \\
&= \frac{1}{2} + p(1)\,(x-r(1)) \quad \text{if } -\frac{1}{2p(1)} + r(1) \leq x \leq \frac{1}{2p(1)} + r(1); \\
&= 1 \quad \text{if } \frac{1}{2p(1)} + r(1) \leq x.
\end{aligned}
$$

Note that curve is completely determined by the baseline value and a number, $p(1)$. The number $p(1)$ is the slope of this curve at the point $x = r(1)$. As with the importance weighting, selection of $p(1)$ is a matter of judgment and can only be done subjectively. One way to establish $p(1)$ is to ask the client to select an improved value, $M(1)$, for the annual production of corn beyond which he is indifferent, or, perhaps more to the point, to select the value of $m(1)$ for the annual production of corn below which he feels would constitute an unacceptable system. In the first case, we would set $p(1)\ \frac{1}{2(M(1)-r(1))}$, and in the second case we would set $p(1) = \frac{1}{w(r(1)-m(1))}$. In the case that the number $p(1)$ is larger, then a small improvement in the production of corn by the system Z will be rewarded with more of the importance weighting assigned to that criterion. If the number $p(1)$ is small, then the improvements in the production of corn will not be well rewarded. Note that there is a point beyond which there is no motive to go.

We can work with our farmer to develop such curves, we can choose them ourselves, or we can estimate them statistically for a population.

Now, given the system Z, we assign to the system Z the quantity:

$$\zeta_\alpha (Z) = w(1)u_1(\zeta_1(Z)) + w(2)u_2(\zeta_2(Z)) + w(3)u_3(\zeta_3(Z)).$$

If we have two systems Z_1 and Z_2, then we say that Z_1 is preferred to Z_2, with respect to input/output performance, if and only if $\zeta_\alpha(Z_1) > \zeta_\alpha(Z_2)$. This is the ordering that we wanted.

Usually we are interested in comparing two systems in the technology cotyledon with respect to costs, the cost to produce, the capital cost, the cost of operation, and so forth, but also with respect to other aspects, such as the length of time to produce or develop the system, reliability, etc.

In the case of systems of agricultural production, besides the factors given above, we are interested in comparing systems in the

technology cotyledon with respect to their resistance to disease, pests, etc. If these aspects are not already in the input/output specifications, they need to be included in the technology merit ordering. This time, we have to ignore the questions of input/output, and to concentrate solely on the questions of the uses of the resources to build and to develop the system.

In order to obtain an ordering over the technology cotyledon, we can proceed by the same method that we used to obtain an ordering over the input/output cotyledon. We attempt to discover all the criteria that our client would want to use to compare any two systems with respect to the utilization of resources, and we attempt to make some sense of these in terms of quantification or observability, or we, at least, try to get them reasonably precisely defined. Then, we try to establish reference values; that is, values for all these criteria in terms of the farmer's present system. On the basis of the baseline value, we can then ask him to give his weights to us as to his feelings with respect to which criteria are in better shape than others, in order to motivate the improvement of his farm system. Then, we can establish the utility curves for each individual criterion and thereby arrive at an overall figure of merit, just as we did in the input/output cotyledon.

The ordering that we have to define over the feasibility cotyledon must be consistent with the other orderings already defined, one over the input/output cotyledon and one over the technology cotyledon, in the following sense: if for two systems Z_1 and Z_2 a decision can be made strictly on the basis of the input/output performance <u>and</u> on the utilization of resources, then it should be done that way. But these would be very special conditions. It will usually be the case that the input/output performance of one system will be much better than the other, but it will cost more. So now we have to have a trade-off between the two. Sometimes we utilize classical trade-offs, such as profits and cost/benefit and that sort of thing, but now, of course, the problem is much more complex because our input/output performance criterion or overall index does not represent a simple benefit by any means, nor does our technology merit ordering represent a simple concept such as cost. These are all very complex now, and the choice of the trade-off merit ordering is something that is more difficult than it was before, but certainly not impossible to achieve.

In order to complete the statement of the problem of the design of a system, we have to relate to the real world the abstract structure of the problem as already defined to this point. To this point, all our considerations can be more or less abstract, dealing with real concepts, of course, but treating them abstractly. At this point, however, it is necessary to relate these abstract considerations to reality. We will do this by defining a test for the real, final system. The definition of the test of the real, final system is part of the statement of the problem; therefore, it is very difficult because the real, final system does not exist at this point. Here we have to describe the methods by means of which we are going to measure and count and observe all the quantities of

which we spoke so glibly above. We have to negotiate the statistical sampling plans, statistical tests, and so forth. We cannot deal with models of systems as we did above. We have to consider what will be done with the real, final system at the end of the project in order to test the system.

Specifically, the test of the real, final system has the following objectives:

1. To give an algorithm, including sampling plans, methods of measurement, of observation, and so forth, by means of which one can calculate or estimate the figure of merit for the real, final system.

2. To give an algorithm by means of which we can decide if the model from which the real, final system was built is an adequate model of the real, final system.

3. To give an algorithm by means of which we can decide if the real, final system is acceptable.

When we have achieved all the things required of us in the statement of the problem algorithm, then we can consider that our problem is well defined, and, as they say, a problem well defined is a problem half solved. In terms of the tricotyledon theory of systems design, to design a system means to develop a model of the system in the feasibility cotyledon determined by an input/output specification and a technology, a model which is optimal with respect to the trade-off ordering, and a model from which a real, final system can be developed which will be acceptable under the system test plan given as part of the statement of the problem.

These concepts will now be applied to the design of systems of production for the small farmer. Since June 1973, the emphasis of the program of research of the Department of Tropical Crops and Soils of CATIE has been "in the search for solutions to the problems of low production that concern the small farmers of Central America and the Caribbean." I assumed, as a systems engineer in residence in the Department, that these words meant that the solution searched for was in the form of a system of agricultural production that would be acceptable to the small farmer, one that he could manage, and one that would be optimal in some sense or other. If this assumption were permissible, we could approach our problem as if we, the technical staff of the Department, were all systems engineers or an interdisciplinary team (which indeed we were) assigned to the design of the system, and as if we had as our client a specific small farmer. In this situation, what ought to have been done first? First, we ought to state our problem as comprehensively and as precisely as possible. The methodology that I recommended in order to accomplish this objective has been summarized above.

The methodology requires that we accomplish seven objectives: (1) to give the problem a name; (2) to define an input/output specification; that

is to say, to identify all the inputs over which our small farmer has no control, and with which the system of the small farmer must contend, and identify all the outputs that the system ought to produce; (4) to define an algorithm by means of which we can decide which of two proposed systems is preferred with respect to the ability of the system to manage the inputs in order to produce the outputs; (5) to define an algorithm by means of which we can decide which of two proposed systems is preferred with respect to use of resources in order to develop and operate the system; (6) to define an algorithm by means of which we can decide which of two proposed systems is preferred with respect to the trade-off between the ability to manage the inputs for the production of the outputs and the use of resources; and (7) to develop a plan by means of which we can test the real, final system that we are going to recommend to our small farmer.

We accomplished one of these objectives immediately. SPUPA (Systema Para Un Pequeño Agricultor) was the name assigned to our problem. Also, we used the name SPUPA in order to refer generically to the system that we were trying to design. The rest of this paper is dedicated to the accomplishment of the other objectives 2 through 7.

Because we did not in reality have as a client a specific small farmer, we had to ascribe to him some characteristics that may not have been appropriate. We did not worry about this aspect in this particular preliminary phase. When we had investigated the characteristics that we knew were going to be of interest to us, then we could launch a research project in order to verify statistically those characteristics in the population of small farmers. Meanwhile, for this particular phase, we had to use the knowledge of the problem held by the members of the Department, as this knowledge had been expressed in writings and conversations with me.

One observes that the methodology obliges us in steps 2 and 3, and again in steps 4 and 5, to separate the considerations of that which the system ought to do from the methods that will be used by the system to accomplish the doing. This is very important in order to avoid confusion. For example, it is possible that the small farmer could desist from the business of agriculture and could start another type of business and still be able to produce corn and beans for his family. We have to decide consciously and clearly by the manner in which we state our problem that such an action is not a viable solution to our problem. In other words, we are going to insist on an agricultural solution to the problem, and this insistence will be embodied in the definition of the technology; that is, the means by which we will build or develop a solution to the problem.

One would observe also that the methodology in steps 4, 5, and 6 requires that we decide beforehand the manner in which we are going to decide with respect to the comparison of systems. The methodology will not permit us to finish our project and not make a decision with respect to which system is the better to recommend for our small farmer. The

methodology does not permit us to be pusillanimous. We have to decide.

If I could avoid it, I did not want to add dimensions to the problem in the first phase. I tried to state the problem according to the methodology more or less formally and precisely, as the problem seemed to me to have been stated tacitly among the members of the technical staff of the Department. If I could accomplish this statement of the problem, then from such a beginning we would be able to improve because we would have a precise and comprehensive statement of the problem, at least to the point where we found ourselves at that moment.

In this section, we will discuss the inputs of SPUPA, the outputs of the system SPUPA, and the limitations that determine which output trajectories can be produced from a given input trajectory. We agreed that the inputs over which the small farmer has no control and which the small farmer has to manage in order to produce the outputs, and the inputs that we could observe at any moment of time are the following:

1.1 Precipitation (mm/day)
1.2 Temperature (^{o}C)
1.3 Relative humidity (%)
1.4 Solar radiation ($kcal/cm^2/day$)
1.5 Sale price of corn ($/mt)
1.6 Sale price of beans ($/mt)
1.7 Sale price of rice ($/mt)
1.8 Sale price of yuca ($/mt)
1.9 Sale price of sweet potatoes ($/mt)

Other inputs that we could have considered are the prices of corn, beans, etc., that the small farmer would have to pay in the market if he wanted to buy these commodities; the price of labor, the price of fertilizer, etc. The last two items one would consider as part of the technological evaluation. At this point, we admitted only as inputs those mentioned above in items 1.1 through 1.9.

The outputs of interest to our small farmer had to be enumerated, and we ignore those outputs that were of interest to us only for the evaluation of systems from the point of view of our research. For example, from this point of view, total biomass was not an output. We wanted to list only those that were of interest to our small farmer. We agreed that the following outputs were those of interest, and those we could observe at any moment of time:

2.1 The quantity of corn (mt/h)
2.2 The quantity of beans (mt/h)
2.3 The quantity of rice (mt/h)
2.4 The quantity of yuca (m/t)
2.5 The quantity of sweet potatoes (mt/h)

2.6 The quantity of protein (kcal/h)
2.7 The quantity of carbohydrates (kcal/h)
2.8 The quantity of fat (kcal/h)
2.9 The total income ($/h)

There were other aspects that we could have included as outputs: physical and chemical characteristics of the soil, the biomass, the production of weeds, and so forth. But at this point we were trying to identify the fundamental reasons for the existence of the systems that we were trying to define. The fundamental reason for the existence of the system SPUPA was to manage the natural inputs of weather and climate and economics in order to produce food and income.

Assume that f is an input trajectory. That is to say, if t is any moment of time, then f(t) would be the observations of the inputs; f(t) is a vector whose components are $(\pi_1(f(t)),\ldots, \pi_9 f(t))$, where $\pi_1(f(t))$ is precipitation, $\pi_2(f(t))$ is the temperature, and $\pi_i(f(t))$ is the observation of the input defined above.

A trajectory g of outputs could be produced from the input trajectory f only if at each time t the total income is less than the sum, over all the commodities produced, of the multiplications of the maximum price of each commodity after the time s of harvest of the commodity and the quantity of the commodity harvested at the time s. In symbols we have:

$$\sum_{s=0}^{t} \pi_9 g(s) \leq \sum_{i=1}^{5} \left(\sum_{s=0}^{t} ((\pi_i(g(s))) \times \max \{\pi_{i+4}(f(u)): u = s, s+1,\ldots,t\}\right).$$

We suspected that there was another limiting relation between the total biomass produced and the total solar radiation received. But, the manner in which we had defined the inputs and the outputs did not enable us to express this relation even if we knew precisely the relationship involved. If such a relation became critical, we would have to modify our input/output specification in order to include this relation in some form.

We adopted the position of the agronomist and assumed that the only methods that we had available to us to solve our problem were agronomical ones. Therefore, a system was specified by means of the following parameters:

3.1 Crops that are planted by variety and classification
3.2 Densities of planting
3.3 Distances of planting
3.4 Dates of planting

3.5 Dates of harvesting
3.6 Machinery used
3.7 Fertilizers applied
3.8 Insecticides applied
3.9 Herbicides applied
3.10 Control of diseases
3.11 Control of birds
3.12 Control of other animals

From writings and conversations, I had identified no less than 57 distinct criteria that had been nominated for use in evaluation of systems of production for the small farmer. Among these, many would have had to be represented by a group of other indices because they are very abstract. For example, "quality of life," as a criterion to evaluate systems of production, is so abstract that it would have required several hundred indices, observations, or measurements to represent it. I assert, however, that any criterion, or quality, or characteristic, however abstract, idealistic, or emotional, can be represented by a group of sensory perceptions that we can observe, measure, or count. Therefore, it was not impossible that we could represent thus the criterion "quality of life," but it was possible that it was not worth representing. Or to say this somewhat differently, it was possible that we did not have sufficient resources to represent such a criterion precisely.

There are some criteria, for example, "stability," that are applicable to all other criteria. We can speak of the stability of production, fertility of the soil, income, and so forth. In each case, we would have had to define "stability" because the concept would be different in each case.

Also, without doubt, I excluded arbitrarily some criteria that some reader would think to be very important. I am sure I also included other criteria that I think are important but which other people do not think are important or for which we did not have available data. By all means, however, ultimately we ought to have negotiated a complete list among the interdisciplinary team, that is, the technical staff of the Department, and the client (or his representatives).

By means of these and other considerations, I reduced the original 57 criteria to the following 34 criteria.

Each quantity or value is an expected value per year in the statistical sense. If i is the name or number of a system, and if a criterion is defined in Section j, then x(i,j) will stand for the value of the criterion defined in Section j for the system i. The value for the criterion defined in Section j for the actual present system for the small farmer will be denoted by r(j):

4.1 The quantity of corn (mt/h)
4.2 The quantity of beans (ht/h)
4.3 The quantity of rice (mt/h)

4.4 The quantity of yuca (mt/h)
4.5 The quantity of sweet potatoes (mt/h)
4.6 The quantity of protein (kcal/h)
4.7 The quantity of carbohydrates (kcal/h)
4.8 The quantity of fat (kcal/h)
4.9 The index of proportion of proteins:

$$\frac{x(i,4.6)}{x(i,4.6) + x(i,4.7) + x(i,4.8)}$$

4.10 The probability of starvation: the probability that

$$x(i,4.6) < \frac{r(4.6)}{2},\ x(i,4.7) < \frac{r(4.7)}{2},\ \text{and } x\ (i,4.8) < \frac{r(4.8)}{2}$$

4.11 The quantity of gross income ($/h)
4.12 The variation of gross income ($/h)
4.13 The index of production in low technology:

$$\sum_{j=4.1}^{4.5} \frac{x(i,j)}{rmb(j)}$$

where rmb(j) is the value of Criterion j that belongs to the system of mono-cropping on which is based the Criterion j with the low level of technology*

4.14 The index of production in high technology:

$$\sum_{j=4.1}^{4.5} \frac{x(i,j)}{rma(j)}$$

where rma(j) is the value of the criterion j that belongs to the system of mono-cropping on which is based the Criterion j with the high level of technology*

4.15 The proportion of time that the land is used
4.16 The cost of fertilizer ($/h)
4.17 The cost of preparing the soil ($/h)
4.18 The value of the land ($/year/h)
4.19 The cost of labor ($/h)

*From the data that we have available and in terms of our present notation we have:

rmb(4.1) = x(3,4.1),	rma(4.1) = x(4,4.1),
rmb(4.2) = x(1,4.2),	rma(4.2) = x(2,4.2),
rmb(4.4) = x(7,4.4),	rma(4.4) = x(8,4.4),
rmb(4.5) = x(5,4.5),	rma(4.5) = x(6,4.5).

For all 25 of the systems to be evaluated subsequently, x(i,4.3) = 0 so the values of rmb(4.3) and rma(4.3) do not make any difference to our analysis.

4.20 The intensity of use of labor (man-days/h)
4.21 The variation of the intensity of use of labor (man-days/h)
4.22 The number of crops
4.23 The production of weeds (mt/h)
4.24 The cost of insecticides ($/h)
4.25 The cost of herbicides ($/h)
4.26 The cost of depreciation and maintenance of equipment and tools ($/h)
4.27 The total cost: x(i,4.16) + x(i,4.17) + (i,4.18) + x(i,4.19) + x(i,4.24) + z(i,4.25) + x(i,4.26)
4.28 The profit: x(i,4.11) - x(i,4.27)
4.29 The return on investment: $\frac{x(i,4.28)}{x(i,4.27)}$
4.30 The return on labor: $\frac{x(i,4.28)}{x(i,4.20)}$
4.31 The photosynthetic efficiency (biomass produced per unit of photosynthetically active solar energy received) (kg/h/kcal)
4.32 The probability of bankruptcy; that is, the probability that x(i,4.28) < 0
4.33 The index of return on investment of land: x(i,4.28) divided by the value of land
4.34 The index of return on investment of time: x(i,4.28) ÷ 365 x (x(i,4.15)).

It was necessary to try to make some sense of the conglomeration of criteria enumerated above. First, we classified the criteria in two groups. The first group contained the criteria that deal purely with the behavior of a system with respect to input/output performance. The second group contained those criteria that treated primarily with the methods to accomplish the performance of input/output behavior.

In the first group, I put the criteria 4.1 to 4.14, and in the second group the criteria 4.15 to 4.34. We will discuss the first group here and the second group below.

In order to compare two systems Z_1 and Z_2 with respect to their behaviors with respect to input/output, it was necessary to combine the 14 criteria in a single index of productivity. I did this in two steps. First, I defined four intermediate indices: an index of absolute productivity, an index of productivity of food, an index of productivity of income, and an index of relative productivity. Second, I combined these indices into a unique index of productivity.

These indices were defined in terms of two mathematical functions. The first function c is of four variables: the value x of a criterion, the value r of the reference value of the criterion, the value p of the slope, and the value w of the importance weighting of the criterion. The function c is defined as follows:

$$
\begin{aligned}
c(x,r,p,w) &= 0 \text{ if } p > 0 \text{ and } x \leq r - \frac{1}{2p} \text{ or} \\
&\qquad \text{if } p < 0 \text{ and } x \geq r - \frac{1}{2p}; \\
&= (\tfrac{1}{2} + p(x-r))w \text{ if } p > 0 \text{ and } r - \frac{1}{2p} < x < r + \frac{1}{2p}, \text{ or} \\
&\qquad \text{if } p < 0 \text{ and } r + \frac{1}{2p} < x < r - \frac{1}{2p}; \\
&= w \text{ if } p > 0 \text{ and } x \geq r + \frac{1}{2p} \text{ or} \\
&\qquad \text{if } p < 0 \text{ and } x \leq r + \frac{1}{2p}.
\end{aligned}
$$

For each criterion j we selected a value p(j) for the slope and a value w(j) of the importance weighting. We also had to obtain a reference value r(j) from the present system of the small farmer.

The second function d is a function of three variables i, a, and b, where i is a name or number of a proposed system, and a and b are numbers of subsections of this section where criteria are defined. One defines the function d as follows:

$$d(i,a,b) = \sum_{j=a}^{b} c(x(j),r(j),p(j),w(j).$$

We always assume that: $\sum_{j=a}^{b} w(j) = 1.$

When one defines:

5.1 The index of productivity is d(i,4.1,4.5).
5.2 The index of production of food is d(i,4.6,4.10).
5.3 The index of productivity of income is d(i,4.11,4.12).
5.4 The index of relative productivity is d(i,4.13,4.14).
5.5 Finally, one defines the index of general productivity as d(i,5.1,5.4).

The weights w(j) and the slope p(j) ought to have been chosen by the small farmer and his representatives, enlightened by extensive discussions with the interdisciplinary team. The reason that we divide the criteria in this manner is in order to facilitate the selection of the weights and the slopes. Nobody can evaluate 14 criteria at one time; it is relatively easy to evaluate three or four related criteria.

If we want to compare two systems Z_1 and Z_2 with respect to their input/output performance, we would compute x(1,5.5) and x(2,5.5) by means of the formulas defined above, and we would say that Z_2 is preferred to Z_1 if and only if x(1,5.5) < x(2,5.5).

The criteria 4.15 to 4.34 are related to the evaluation of systems with respect to the use of resources and the method by means of which the systems accomplish their objectives. As before, we divided these smaller groups and defined intermediate criteria that we could treat more easily:

6.1 The index of the use of land is d(i,4.15,4.18)
6.2 The index of use of labor is d(i,4.19,4.26)
6.3 The index of profitability is d(i,4.27,4.34)
6.4 One then arrives to define the index of technology as x(i,6.1) x x(i,6.2) + x(i,6.3)

I chose another form for the index of technology (6.4) because I wanted the indices of use of soil and of the use of labor to be optimized jointly, while the index of profitability is optimized independently.

If we would want to compare the systems Z_1 and Z_2 with respect to the use of resources, we would compute x(1,6.4) and x(2,6.4) by means of the formulas defined above, and we would say that Z_2 is preferred to Z_1 if and only if x(1,6.4) < x(2,6.4).

These computations can be accomplished based on experimental data generated in the field, or based on data derived from mathematical models of the systems.

The next step was to define a merit ordering that would be a trade-off between the input/output merit ordering and the technology merit ordering, respectively. We accomplished this step by defining the feasibility index: x(i,7) = x(i,5.5) + x(i,6.4).

This expression represents profit in a very general way because, specifically, profit is income minus cost; in our case, x(i,5.5) represents income, very generalized, and x(i,6.4) represents, in a way, the negative of cost, very generalized also.

If we would want to compare two systems Z_1 and Z_2 with respect to the trade-off between input/output performance and the use of resources, we would compute x(1,7) and x(2,7) by means of the formula defined above, and we would say that Z_2 is preferred to Z_1 if and only if x(1,7) < x(2,7). This is the last criterion and the most important for the comparison and evaluation of proposed systems.

From the point of view of the systems engineer, the process of the design of a system consists in stating the problem, developing mathematical models of systems (perhaps by means of computers), studying these models, and, finally, developing the real system by means of a model well-optimized. The programs of investigation in the laboratory and the field would be coordinated with this process with the objectives: to discover the basic information concerning causal relations involved in the natural

processes being studied and to test the quality of the models developed against reality.

In terms already defined, we ought to have developed models of systems determined by values of parameters (3.1 to 3.12) of the technology enumerated on page 131 such that if we would introduce an input trajectory as described on pages 124 - 126, we would be able to deduce the trajectory of outputs that would be produced by a system thus specified.

But before we could launch a project to develop models of systems of agricultural production, we had to define the plan by means of which we were going to test the real system finally developed from our optimized model. This plan ought to provide the methods to answer the following questions:

(1) How does one measure in the field the input/output behavior and the use of resources of the real system? In order to respond to this question, it would be necessary to know the size of the sample that we ought to collect, when to collect it, how to collect it, what the methods are to be used to measure or count or observe, and how to record them. This information ought to have been specified for each one of the criteria defined abstractly above.

(2) Is the optimized model an adequate model of the real system? That is to say, can we predict the behavior of the real system with sufficient precision by means of the model system? Here we have to specify the relations that interest us between the model and the real system. We have to define the words "predict" and "precision" in this context.

(3) Is the real system acceptable to the client? Are there other tests or computations or attributes that we ought to consider, or other criteria that we have omitted above?

Only when we had written such a plan to test the real, final system could we consider that our problem was well-stated, and we, secure in the knowledge that we were not going to waste our time or other resources, could launch a project to develop models of systems of agricultural production.

Obviously, the experiments in the field must be considered to be of two classes: The class of experiments to provide information to the process of the development of the model, and the class of experiments to test real, final systems. The two classes of experiments have different objectives, and we ought to clarify which are the objectives of our experiments.

To discuss in more detail such a plan to test systems would extend this document far beyond what is reasonable, and would require contributions from other specialists. So we shall move on.

In order to illustrate the process of the evaluation of systems as discussed above, I have computed the necessary values in order to evaluate the 25 systems based on the data of the last agricultural year 1974-75.

Required for these computations are values for the weights w(j), the slopes p(j), and the value r(j) corresponding to the present system of the small farmer. The values w(j) and p(j) ought to have resulted from dialogues between the client and/or his representatives and the interdisciplinary team. Lacking such dialogues, I have applied my own value judgments. The values of the slopes p(j), in this case, were almost all chosen to be equal to +1/2 or -1/2. The value of the weights were chosen in each case arbitrarily to reflect my own judgments as to the relative importance of the various criteria. If there were no values available for criteria j, I have assumed that x(i,j) = r(j) for each of the systems i. To represent the actual present system for the small farmer, I have chosen the system numbered 14, that is to say, r(j) = x(14,j) for each value of j = 4.1 to 4.34.

The principal results of the computation appear in Table 1. Before discussing the results, however, let us refer to a typical worksheet on page 143. In the left-hand column are given numbers from one to 25 as well as system characterizations: F stands for fréjoles, M for maiz, M/M/M means a rotation of a maiz crop throughout the growing year, and C/C is a camote/camote rotation. System 9 characterized by F+M means that fréjoles and maiz are grown in the same plot simultaneously. In system 14 we have fréjoles, maiz, and yuca in the same plot at the same time. In system 22 we have maiz and yuca growing at the same time and then being replaced by camote later on in the growing season. Each of these systems was also characterized by whether they were grown in high technology or low technology. High technology means herbicides, fertilizer, insecticides, and machinery, all the green revolution technology. High technology is indicated by an "A" in the right half of the second column. A "B" in the right half of the second column means low technology, which is just about the slash and burn kind of technology used by the peasant farmers in Costa Rica. The rest of the worksheet indicates the data that had actually been collected in the field by the Department of Tropical Crops and Soils on each of these systems in one field trial for one year. The valuation column indicates the evaluation of that data with respect to the weights and utility curve that we have discussed earlier. Such computation is carried out for each one of the 34 criteria and for each one of the 25 systems for which we have data available. The "rolling up" of all of this data and those indices results in the table given on the next page where we have the system characterizations in the left-hand column and values indicated of the intermediate indices of absolute productivity, productivity of food, productivity of income, relative productivity, and general productivity; then use of land, use of labor, profitability, and general resource utilization indices. The value or the trade-off feasibility index is given in the last column.

TABLE 1

j→ i↓	CHARACTERIZATION		ABSOLUTE PRODUCTIVITY 5.1	PRODUCTIVITY OF FOOD 5.2	PRODUCTIVITY OF INCOME 5.3	RELATIVE PRODUCTIVITY 5.4	GENERAL PRODUCTIVITY 5.5	USE OF LAND 6.1	USE OF LABOR 6.2	PROFITABILITY 6.3	GENERAL RESOURCE UTILIZATION 6.4	TRADEOFF FEASIBILITY 7
1	F	B	0.35	0.07	0.15	0.08	0.33	0.42	0.46	0.18	0.37	0.70
2	F	A	0.46	0.54	0.15	0.82	0.45	0.42	0.46	0.24	0.43	0.88
3	M/M/M	B	0.49	0.29	0.15	0.08	0.38	0.46	0.46	0.18	0.39	0.77
4	M/M/M	A	0.49	0.66	0.15	0.82	0.47	0.46	0.46	0.27	0.48	0.95
5	C/C	B	0.34	0.72	0.85	0.27	0.58	0.47	0.51	0.77	1.01	1.59
6	C/C	A	0.34	0.47	0.85	0.22	0.53	0.47	0.47	0.49	0.71	1.24
7	Y	B	0.53	0.29	0.15	0.12	0.39	0.50	0.46	0.34	0.57	0.96
8	Y	A	0.53	0.66	0.85	0.42	0.59	0.50	0.46	0.46	0.69	1.28
9	F+M	A	0.53	0.60	0.15	0.96	0.47	0.46	0.46	0.30	0.51	0.98
10	F+Y	B	0.55	0.66	0.85	0.48	0.59	0.50	0.48	0.45	0.69	1.28
11	F+Y	A	0.69	0.72	0.85	1.00	0.63	0.50	0.46	0.32	0.55	1.18
12	M+Y	B	0.55	0.72	0.15	0.70	0.48	0.50	0.46	0.34	0.57	1.05
13	M+Y	A	0.59	0.72	0.15	0.97	0.50	0.50	0.46	0.31	0.54	1.04
14	F+M+Y	B	0.50	0.50	0.50	0.50	0.50	0.82	0.50	0.50	0.91	1.41
15	F+M+Y	A	0.77	0.72	0.85	0.98	0.64	0.50	0.47	0.36	0.60	1.24
16	F+Y→M	B	0.61	0.72	0.85	0.90	0.62	0.59	0.50	0.42	0.72	1.34
17	F+Y→M	A	0.79	0.72	0.85	1.00	0.64	0.59	0.47	0.40	0.58	1.22
18	F→M→M	A	0.66	0.60	0.15	1.00	0.48	0.59	0.46	0.11	0.38	0.86
19	F+M→M	A	0.59	0.60	0.15	1.00	0.47	0.55	0.46	0.11	0.36	0.83
20	M+Y→M	B	0.59	0.29	0.15	0.46	0.40	0.59	0.48	0.26	0.54	0.94
21	M+Y→M	A	0.72	0.72	0.85	1.00	0.63	0.59	0.46	0.30	0.57	1.20
22	M+Y→C	B	0.76	0.72	0.85	1.00	0.64	0.59	0.48	0.31	0.59	1.23
23	M+Y→C	A	0.51	0.72	0.85	1.00	0.62	0.59	0.49	0.22	0.51	1.12
24	C+Y→C	B	0.34	0.72	0.85	1.00	0.60	0.59	0.52	0.29	0.60	1.20
25	C+Y→C	A	0.57	0.72	0.85	1.00	0.62	0.59	0.51	0.33	0.63	1.25

The last column of the table wherein are displayed a summary of the principal results, shows us that the system numbered 5 characterized as C/C,B is the best system. The second system from the point of view of the trade-off index is the system numbered 14, the system that was taken as reference, and the third system is the system numbered 16. Therefore, we would have to say to our small farmer that, based on all our data of the past year, and under all the assumptions that are represented in the discussion above, and the given selection of weights and slopes, we would recommend that he adopt the system numbered 5.

Note that all of these three "winners" are in the low technology currently in use by the small farmers of Costa Rica. Of course, these results are not terribly conclusive simply because they were computed on the bases not of weights and slopes and utuility functions of any particular small farmer, but just those that I had estimated or conjured by conversations. In any event, upon display of these results a great deal of animated conversation ensued among the staff of the Department simply because the people on the staff were beginning to ask themselves why these particular systems seem to come out ahead in the calculations and the overall evaluation. This led to very instructive and constructive discussions. It became clear that if the results were not pleasing, then it would be necessary to change the statement of the problem to obtain better weights and better utility functions, and so on, or else to change some other aspect of the problem. When we have confidence that we have actually captured the peasant farmer's problem, then we can begin to practice synthesis of solutions in the classical engineering sense and perhaps arrive at some truly creative solutions to the problem.

This is only a beginning toward the application of systems engineering methodology for introduction of modern agricultural technology in developing countries. This is a rigorous methodology, that can be used to find out exactly what kind of technology we ought to be introducing, and to improve our performance with respect to the development of those countries.

* * *

Discussion

Q. It looks to me like you based your evaluation on how the people involved would make choices in particular situations. Thus, perhaps your results which show the current system to be the optimum arrangement results from the method itself.

A. No question about that. It's because, after all, it was these people for whom we were trying to design the system. What we did was, if we wanted to find out how to devise the model, we talked to persons at the lab and put their value judgment into the statement of the problem. Based on their position they would have put

very low weights on risk aversion factors, and very high weights on production. To make this more general, you would have to incorporate a lot more information which is difficult to come by. What is the probability that I can sell this model and approach to the small farmer? You have to trade-off between different choices and it all depends on whose value goes into this thing. In this particular case, our clients said that you had to sell it to the small farmer, he's your essential point, and that's whose value system, as related by the lab personnel, we tried to incorporate, so that's the way it came out.

Q. Does your model take into account that amount of diversity a farmer must have because of the built-in feeling that there can be catastrophies?

A. Yes, we certainly included that. For example, we have one index that we identified which was the probability of starvation. We defined that as being zero, since the value for any system of carbohydrate, protein, and fat root cells alone have enough value to prevent starvation. We also incorporated the probability of bankruptcy; that is, the probability that his net income fell below one half of his present income.

Q. How big of a sample do you need to define the model when you are working on a national problem so that you are able to come up with a national value judgment?

A. You have to be very hard-nosed about it at all times, and be very clear about who the client really is. If the government is paying the bill, in a sense, it is buying the right to have its value judgment used to evaluate the alternatives. If you want to design a system to extract individual values, then another system designed on all its own rights is needed. But, on the other hand, if we are really designing a system for AID, then their expectations would be used. I would ask:what are the values? They would probably put a big weight on productivity increases, and so forth, and it seems to me you would have to clearly identify the client. He is the person whose values get included.

Q. Is the response of the system guaranteed to give a result that coincides with the person's value judgments? Or is there some system there that is allowed to actually present a result that conflicts with the person's value judgment?

A. Well, the whole methodology is geared to minimize the probability that what you come up with will not be acceptable to him. As a matter of fact, the critical system test is to determine what you are going to do to the system to decide whether or not the actual system it predicts is acceptable or not. Well, what more can you do? That is, other than involving the client in every step of the system design; if the client is going to stand there all the time

and make all the decisions I make, then we wouldn't have to go through this exercise. You could say:"O.K., now we have got to make a decision on this. What do you think?" and he would say: "Well, O.K. we'll do it this way."

Q. How do you know he is consistent?

A. He probably isn't consistent, and he may not like the way it comes out, but in any event what you really want is some surrogate, some model of his value judgment, an understandable structure, an abstract structure that the next generation systems guy can understand, and he'll come back and say: "Well, the problem with this system and the reason it doesn't work good enough is because they didn't put enough weight on this thing, or they didn't include that criteria." Because you can see from the documentation of the last system, all the criteria were used and the weights were put on. Now, if the system doesn't work, why not? For example, part of the reason our social systems do not appear to us to be working now is because we are applying different criteria to them than those for which they were originally designed. The same is true for a lot of the environmental problems we are seeing now. You know, the guy who designed a plan 30 or 40 years ago had a set of criteria that were valid to him, and he designed the optimal point. Now, years later, we are saying he was wrong. Well, that wasn't part of the criterion at that time. If you now want to have a new system which is properly designed for the criteria, you will have to design a new system. But even the new system may not be perfect. There is no guarantee anywhere, is there? The only thing you can do is to apply whatever intellectual modifications you can, and hope to take this into account in such a way that you minimize it a lot.

(Editors' Note: The worksheets referred to in Dr. Wymore's paper are reproduced on the next eleven pages.)

j →	CHARACTERIZATION		PRODUCTION OF CORN		PRODUCTION OF BEANS		PRODUCTION OF RICE		PRODUCTION OF YUCA	
			3.4.1		3.4.2		3.4.3		3.4.4	
p(j) →			0.5		0.5		0.5		0.5	
w(j) →			0.23		0.31		0.15		0.23	
i ↓			DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION
1	F	B	0.0	0.036	0.35	0.2	0.0	0.075	0.0	0.0
2	F	A	0.0	0.036	1.08	0.31	0.0	0.075	0.0	0.0
3	M/M/M	B	1.68	0.229	0.0	0.146	0.0	0.075	0.0	0.0
4	M/M/M	A	5.82	0.23	0.0	0.146	0.0	0.075	0.0	0.0
5	C/C	B	0.0	0.036	0.0	0.146	0.0	0.075	0.0	0.0
6	C/C	A	0.0	0.036	0.0	0.146	0.0	0.075	0.0	0.0
7	Y	B	0.0	0.036	0.0	0.146	0.0	0.075	7.86	0.23
8	Y	A	0.0	0.036	0.0	0.146	0.0	0.075	14.71	0.23
9	F+M	A	0.60	0.105	2.92	0.31	0.0	0.075	0.0	0.0
10	F+Y	B	0.0	0.036	0.17	0.172	0.0	0.075	12.52	0.23
11	F+Y	A	0.0	0.036	1.04	0.307	0.0	0.075	19.13	0.23
12	M+Y	B	1.23	0.177	0.0	0.146	0.0	0.075	8.41	0.115
13	M+Y	A	3.05	0.23	0.0	0.146	0.0	0.075	8.30	0.102
14	F+M+Y	B	0.69	0.115	0.06	0.155	0.0	0.075	8.41	0.115
15	F+M+Y	A	1.61	0.221	0.37	0.203	0.0	0.075	12.18	0.23
16	F+Y→M	B	0.51	0.094	0.15	0.169	0.0	0.075	13.94	0.23
17	F+Y→M	A	0.93	0.143	1.03	0.305	0.0	0.075	18.59	0.23
18	F→M→M	A	3.14	0.23	1.36	0.31	0.0	0.075	0.0	0.0
19	F+M→M	A	3.84	0.23	0.63	0.243	0.0	0.075	0.0	0.0
20	M+Y→M	B	0.53	0.097	0.0	0.146	0.0	0.075	5.7	0.23
21	M+Y→M	A	3.44	0.23	0.0	0.146	0.0	0.075	9.79	0.23
22	M+Y→C	B	1.85	0.23	0.0	0.146	0.0	0.075	10.68	0.23
23	M+Y→C	A	3.0	0.23	0.0	0.146	0.0	0.075	7.32	0.0
24	C+Y→C	B	0.0	0.036	0.0	0.146	0.0	0.075	4.99	0.0
25	C+Y→C	A	0.0	0.036	0.0	0.146	0.0	0.075	15.84	0.23

j →	CHARACTERIZATION		PRODUCTION OF CAMOTE		PRODUCTION OF PROTEIN		PRODUCTION OF CARBOHYDRATES		PRODUCTION OF FAT	
p(j)→			3.4.5		3.4.6		3.4.7		3.4.8	
w(j)→			0.5		0.5		0.5		0.5	
			0.08		0.25		0.12		0.06	
i ↓			DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION
1	F	B	0.0	0.04	250	0.0	1649	0.0	24	0.0
2	F	A	0.0	0.04	770	0.25	5089	0.0	81	0.0
3	M/M/M	B	0.0	0.04	194	0.0	4244	0.0	117	0.0
4	M/M/M	A	0.0	0.04	677	0.25	14798	0.0	415	0.06
5	C/C	B	16.33	0.08	656	0.25	46278	0.12	375	0.06
6	C/C	A	12.84	0.08	503	0.0	35572	0.12	290	0.06
7	Y	B	0.0	0.04	292	0.0	21511	0.0	109	0.0
8	Y	A	0.0	0.04	548	0.25	41632	0.12	202	0.0
9	F+M	A	0.0	0.04	1213	0.25	20046	0.0	525	0.06
10	F+Y	B	0.0	0.04	588	0.25	36243	0.12	185	0.0
11	F+Y	A	0.0	0.04	1454	0.25	59050	0.12	339	0.06
12	M+Y	B	0.0	0.04	644	0.25	31052	0.12	319	0.06
13	M+Y	A	0.0	0.04	1131	0.25	41474	0.12	617	0.06
14	F+M+Y	B	0.0	0.04	542	0.125	28157	0.06	234	0.03
15	F+M+Y	A	0.0	0.04	1151	0.25	45709	0.12	459	0.06
16	F+Y→M	B	0.0	0.04	765	0.25	43173	0.12	286	0.06
17	F+Y→M	A	0.0	0.04	1679	0.25	62959	0.12	484	0.06
18	F→M→M	A	0.0	0.04	1818	0.25	24917	0.0	617	0.06
19	F+M→M	A	0.0	0.04	1480	0.25	25612	0.0	682	0.06
20	M+Y→M	B	0.0	0.04	357	0.0	19267	0.0	166	0.0
21	M+Y→M	A	0.0	0.04	1289	0.25	48002	0.12	701	0.06
22	M+Y→C	B	2.15	0.08	984	0.25	97424	0.12	503	0.06
23	M+Y→C	A	0.38	0.055	1097	0.25	39523	0.12	605	0.06
24	C+Y→C	B	8.76	0.08	550	0.25	34317	0.12	279	0.06
25	C+Y→C	A	2.65	0.08	700	0.25	49048	0.12	282	0.06

j →	CHARACTERIZATION		PROPORTION OF PROTEIN		PROBABILITY OF FAMINE		GROSS INCOME		VARIATION OF GROSS INCOME	
			3.4.9		3.4.10		3.4.11		3.4.12	
p(j) →			0.5		- 0.5		0.5		- 0.5	
w(j) →			0.13		0.44		0.7		0.3	
i ↓			DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION
1	F	B	0.13	0.073	1	0.0	120.33	0.0	-	0.15
2	F	A	0.13	0.073	0	0.22	395.99	0.0	-	0.15
3	M/M/M	B	0.04	0.067	0	0.22	96.90	0.0	-	0.15
4	M/M/M	A	0.04	0.067	0	0.22	336.77	0.0	-	0.15
5	C/C	B	0.01	0.065	0	0.22	2037.77	0.7	-	0.15
6	C/C	A	0.01	0.065	0	0.22	1566.33	0.7	-	0.15
7	Y	B	0.01	0.065	0	0.22	986.41	0.0	-	0.15
8	Y	A	0.01	0.065	0	0.22	1943.27	0.7	-	0.15
9	F+M	A	0.05	0.068	0	0.22	611.77	0.0	-	0.15
10	F+Y	B	0.01	0.065	0	0.22	1396.63	0.7	-	0.15
11	F+Y	A	0.02	0.066	0	0.22	1433.08	0.7	-	0.15
12	M+Y	B	0.02	0.066	0	0.22	867.63	0.0	-	0.15
13	M+Y	A	0.02	0.066	0	0.22	1085.80	0.0	-	0.15
14	F+M+Y	B	0.01	0.065	0	0.22	1124.29	0.35	-	0.15
15	F+M+Y	A	0.02	0.066	0	0.22	1685.20	0.7	-	0.15
16	F+Y→M	B	0.01	0.065	0	0.22	1649.64	0.7	-	0.15
17	F+Y→M	A	0.02	0.066	0	0.22	2537.76	0.7	-	0.15
18	F→M→M	A	0.06	0.068	0	0.22	919.95	0.0	-	0.15
19	F+M→M	A	0.05	0.068	0	0.22	746.21	0.0	-	0.15
20	M+Y→M	B	0.01	0.065	0	0.22	433.82	0.0	-	0.15
21	M+Y→M	A	0.02	0.066	0	0.22	1301.45	0.7	-	0.15
22	M+Y→C	B	0.02	0.066	0	0.22	1685.69	0.7	-	0.15
23	M+Y→C	A	0.02	0.066	0	0.22	1252.89	0.7	-	0.15
24	C+Y→C	B	0.01	0.065	0	0.22	1674.67	0.7	-	0.15
25	C+Y→C	A	0.01	0.065	0	0.22	2075.57	0.7	-	0.15

j →	CHARACTERIZATION		PRODUCTION IN COIN TECHNOLOGY		PRODUCTION IN HIGH TECHNOLOGY		TIME OF USE OF LAND		COST OF FERTILIZERS	
			3.4.13		3.4.14		3.4.15		3.4.16	
p(j)→			0.5		0.5		0.5		- 0.5	
w(j)→			0.6		0.4		0.37		0.11	
i ↓			DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION
1	F	B	1.0	0.0	0.32	0.08	0.23	0.105	-	0.055
2	F	A	3.09	0.6	1.0	0.22	0.22	0.105	-	0.055
3	M/M/M	B	1.0	0.0	0.29	0.08	0.45	0.146	-	0.055
4	M/M/M	A	3.46	0.6	1.0	0.22	0.45	0.146	-	0.055
5	C/C	B	1.0	0.0	1.27	0.27	0.47	0.150	-	0.055
6	C/C	A	0.79	0.0	1.0	0.22	0.47	0.150	-	0.055
7	Y	B	1.0	0.0	0.53	0.12	0.66	0.185	-	0.055
8	Y	A	1.87	0.2	1.0	0.22	0.66	0.185	-	0.055
9	F+M	A	5.77	0.6	1.72	0.36	0.45	0.146	-	0.055
10	F+Y	B	2.08	0.26	1.01	0.22	0.66	0.185	-	0.055
11	F+Y	A	5.4	0.6	2.26	0.4	0.66	0.185	-	0.055
12	M+Y	B	2.78	0.47	1.06	0.23	0.66	0.185	-	0.055
13	M+Y	A	5.3	0.6	1.78	0.37	0.66	0.185	-	0.055
14	F+M+Y	B	2.2	0.3	0.91	0.2	0.66	0.185	-	0.055
15	F+M+Y	A	4.85	0.6	1.81	0.38	0.66	0.185	-	0.055
16	F+Y→M	B	4.02	0.6	1.41	0.3	1.12	0.27	-	0.055
17	F+Y→M	A	8.63	0.6	2.89	0.4	1.12	0.27	-	0.055
18	F→M→M	A	11.8	0.6	3.22	0.4	1.14	0.274	-	0.055
19	F+M→M	A	10.38	0.6	2.62	0.4	0.91	0.231	-	0.055
20	M+Y→M	B	2.19	0.3	0.71	0.16	1.12	0.270	-	0.055
21	M+Y→M	A	7.79	0.6	2.32	0.4	1.12	0.27	-	0.055
22	M+Y→C	B	8.15	0.6	4.63	0.4	1.13	0.272	-	0.055
23	M+Y→C	A	5.85	0.6	2.26	0.4	1.13	0.272	-	0.055
24	C+Y→C	B	5.73	0.6	3.65	0.4	1.13	0.272	-	0.055
25	C+Y→C	A	4.48	0.6	2.98	0.4	1.13	0.272	-	0.055

j →	CHARACTERIZATION		COST OF PREPARATION OF SOIL		RENT OF LAND		COST OF LABOR		INTENSITY OF USE OF LABOR	
p(j)→			3.4.17		3.4.18		3.4.19		3.4.20	
w(j)→			-0.5		-0.5		-0.5		-0.5	
i ↓			0.15		0.37		0.23		0.19	
			DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION
1	F	B	—	0.075	—	0.185	—	0.115	—	0.095
2	F	A	—	0.075	—	0.185	—	0.115	—	0.095
3	M/M/M	B	—	0.075	—	0.185	—	0.115	—	0.095
4	M/M/M	A	—	0.075	—	0.185	—	0.115	—	0.095
5	C/C	B	—	0.075	—	0.185	—	0.115	—	0.095
6	C/C	A	—	0.075	—	0.185	—	0.115	—	0.095
7	Y	B	—	0.075	—	0.185	—	0.115	—	0.095
8	Y	A	—	0.075	—	0.185	—	0.115	—	0.095
9	F+M	A	—	0.075	—	0.185	—	0.115	—	0.095
10	F+Y	B	—	0.075	—	0.185	—	0.115	—	0.095
11	F+Y	A	—	0.075	—	0.185	—	0.115	—	0.095
12	M+Y	B	—	0.075	—	0.185	—	0.115	—	0.095
13	M+Y	A	—	0.075	—	0.185	—	0.115	—	0.095
14	F+M+Y	B	—	0.075	—	0.185	—	0.115	—	0.095
15	F+M+Y	A	—	0.075	—	0.185	—	0.115	—	0.095
16	F+Y→M	B	—	0.075	—	0.185	—	0.115	—	0.095
17	F+Y→M	A	—	0.075	—	0.185	—	0.115	—	0.095
18	F→M→M	A	—	0.075	—	0.185	—	0.115	—	0.095
19	F+M→M	A	—	0.075	—	0.185	—	0.115	—	0.095
20	M+Y→M	B	—	0.075	—	0.185	—	0.115	—	0.095
21	M+Y→M	A	—	0.075	—	0.185	—	0.115	—	0.095
22	M+Y→C	B	—	0.075	—	0.185	—	0.115	—	0.095
23	M+Y→C	A	—	0.075	—	0.185	—	0.115	—	0.095
24	C+Y→C	B	—	0.075	—	0.185	—	0.115	—	0.095
25	C+Y→C	A	—	0.075	—	0.185	—	0.115	—	0.095

j →			VARIATION OF USE OF LABOR		NUMBER OF CROPS		PRODUCTION OF WEEDS		COST OF INSECTICIDES	
p(j) →			3.4.21		3.4.22		3.4.23		3.4.24	
w(j) →			-0.5		0.5		-0.5		-0.5	
			0.19		0.02		0.06		0.09	
i ↓	CHARACTERIZATION		DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION
1	F	B	—	0.095	1	0.0	6.0	0.0	—	0.045
2	F	A	—	0.095	1	0.0	8.0	0.0	—	0.045
3	M/M/M	B	—	0.095	1	0.0	5.42	0.0	—	0.045
4	M/M/M	A	—	0.095	1	0.0	5.52	0.0	—	0.045
5	C/C	B	—	0.095	1	0.0	2.0	0.05	—	0.045
6	C/C	A	—	0.095	1	0.0	3.20	0.014	—	0.045
7	Y	B	—	0.095	1	0.0	4.38	0.0	—	0.045
8	Y	A	—	0.095	1	0.0	3.86	0.0	—	0.045
9	F+M	A	—	0.095	2	0.0	7.86	0.0	—	0.045
10	F+Y	B	—	0.095	2	0.0	2.9	0.023	—	0.045
11	F+Y	A	—	0.095	2	0.0	3.66	0.0	—	0.045
12	M+Y	B	—	0.095	2	0.0	3.92	0.0	—	0.045
13	M+Y	A	—	0.095	2	0.0	5.62	0.0	—	0.045
14	F+M+Y	B	—	0.095	3	0.1	2.66	0.03	—	0.045
15	F+M+Y	A	—	0.095	3	0.01	5.3	0.0	—	0.045
16	F+Y→M	B	—	0.095	3	0.01	2.6	0.032	—	0.045
17	F+Y→M	A	—	0.095	3	0.01	4.76	0.0	—	0.045
18	F→M→M	A	—	0.095	2	0.0	4.94	0.0	—	0.045
19	F+M→M	A	—	0.095	2	0.0	5.68	0.0	—	0.045
20	M+Y→M	B	—	0.095	2	0.0	2.92	0.022	—	0.045
21	M+Y→M	A	—	0.095	2	0.0	6.82	0.0	—	0.045
22	M+Y→C	B	—	0.095	3	0.01	3.28	0.011	—	0.045
23	M+Y→C	A	—	0.095	3	0.01	3.06	0.018	—	0.045
24	C+Y→C	B	—	0.095	2	0.0	1.32	0.06	—	0.045
25	C+Y→C	A	—	0.095	2	0.0	2.12	0.046	—	0.045

j → p(j) → w(j) → i ↓	CHARACTERIZATION	COST OF HERBICIDES		COST OF DEPRECIATION AND MAINTENANCE		TOTAL COST		PROFIT	
		3.4.25 -0.5 0.09		3.4.26 -0.5 0.13		3.4.27 -0.00125 0.18		3.4.28 0.0005 0.22	
		DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION
1	F	–	0.045	–	0.065	261.07	0.075	-132.74	0.0
2	F	–	0.045	–	0.065	340.35	0.057	55.64	0.014
3	M/M/M/	–	0.045	–	0.065	263.44	0.075	-166.84	0.0
4	M/M/M/	–	0.045	–	0.065	264.01	0.075	72.76	0.016
5	C/C	–	0.045	–	0.065	230.07	0.082	1807.70	0.207
6	C/C	–	0.045	–	0.065	366.68	0.051	1199.65	0.140
7	Y	–	0.045	–	0.065	326.53	0.061	659.88	0.08
8	Y	–	0.045	–	0.065	497.84	0.022	1445.43	0.167
9	F+M	–	0.045	–	0.065	304.97	0.065	306.80	0.042
10	F+Y	–	0.045	–	0.065	317.98	0.062	1078.65	0.126
11	F+Y	–	0.045	–	0.065	586.54	0.002	846.54	0.101
12	M+Y	–	0.045	–	0.065	278.03	0.071	589.60	0.073
13	M+Y	–	0.045	–	0.065	434.18	0.036	651.62	0.08
14	F+M+Y	–	0.045	–	0.065	195.49	0.09	928.80	0.11
15	F+M+Y	–	0.045	–	0.065	601.95	0.0	1083.25	0.127
16	F+Y→M	–	0.045	–	0.065	644.30	0.0	1005.34	0.118
17	F+Y→M	–	0.045	–	0.065	985.13	0.0	1552.63	0.179
18	F→M→M	–	0.045	–	0.065	957.77	0.0	-37.82	0.004
19	F+M→M	–	0.045	–	0.065	750.82	0.0	-4.61	0.007
20	M+Y→M	–	0.045	–	0.065	293.77	0.068	140.05	0.023
21	M+Y→M	–	0.045	–	0.065	531.03	0.015	770.42	0.093
22	M+Y→C	–	0.045	–	0.065	724.17	0.0	961.52	0.114
23	M+Y→C	–	0.045	–	0.065	912.59	0.0	346.30	0.045
24	C+Y→C	–	0.045	–	0.065	892.46	0.0	782.21	0.094
25	C+Y→C	–	0.045	–	0.065	1035.13	0.0	1040.44	0.122

j →			RETURN ON INVESTMENT		RETURN ON LABOR		PHOTOSYNTHETIC EFFICIENCY		PROBABILITY OF BANKRUPTCY	
p(j) →			3.4.29		3.4.30		3.4.31		3.4.32	
w(j) →			0.2		0.5		0.5		-0.5	
i ↓	CHARACTERIZATION		0.16		0.15		0.02		0.13	
			DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION	DATA	EVALUATION
1	F	B	-0.51	0.0	—	0.075	0.09	0.008	1	0
2	F	A	0.16	0.0	—	0.075	0.1	0.008	0	0.065
3	M/M/M	B	-0.63	0.0	—	0.075	0.41	0.011	1	0.0
4	M/M/M	A	0.28	0.0	—	0.075	0.97	0.017	0	0.065
5	C/C	B	7.86	0.16	—	0.075	0.33	0.01	0	0.065
6	C/C	A	3.27	0.033	—	0.075	0.48	0.012	0	0.065
7	Y	B	2.02	0.0	—	0.075	0.22	0.009	0	0.065
8	Y	A	2.90	0.021	—	0.075	0.34	0.01	0	0.065
9	F+M	A	1.01	0.0	—	0.075	0.38	0.011	0	0.065
10	F+Y	B	3.39	0.036	—	0.075	0.3	0.01	0	0.065
11	F+Y	A	1.44	0.0	—	0.075	0.31	0.01	0	0.065
12	M+Y	B	2.12	0.0	—	0.075	0.2	0.009	0	0.065
13	M+Y	A	1.5	0.0	—	0.075	0.44	0.11	0	0.065
14	F+M+Y	B	4.75	0.08	—	0.075	0.31	0.01	0	0.065
15	F+M+Y	A	1.8	0.0	—	0.075	0.59	0.013	0	0.065
16	F+Y→M	B	1.56	0.0	—	0.075	0.25	0.009	0	0.065
17	F+Y→M	A	1.58	0.0	—	0.075	0.27	0.01	0	0.005
18	F→M→M	A	-0.04	0.0	—	0.075	0.24	0.009	1	0.0
19	F+M→M	A	-0.01	0.0	—	0.075	0.20	0.009	1	0.0
20	M+Y→M	B	0.48	0.0	—	0.075	0.12	0.008	0	0.065
21	M+Y→M	A	1.45	0.0	—	0.075	0.33	0.01	0	0.065
22	M+Y→C	B	1.33	0.0	—	0.075	0.24	0.009	0	0.005
23	M+Y→C	A	0.37	0.0	—	0.075	0.39	0.011	0	0.065
24	C+Y→C	B	0.88	0.0	—	0.075	0.23	0.009	0	0.065
25	C+Y→C	A	0.01	0.0	—	0.075	0.38	0.011	0	0.065

j →	CHARACTERIZATION		RETURN ON LAND		RETURN PER TIME		ABSOLUTE PRODUCTIVITY		PRODUCTIVITY OF FOOD	
p(j)→			3.4.33		3.4.34		3.5.1		3.5.2	
w(j)→			0.5		0.15		0.5		0.5	
			0.05		0.09		0.17		0.39	
i ↓			DATA	EVALUATION	DATA	EVALUATION	VALUE	EVALUATION	VALUE	EVALUATION
1	F	B	-0.04	0.018	-1.58	0.0	0.35	0.072	0.07	0.111
2	F	A	0.02	0.019	0.66	0.002	0.46	0.082	0.54	0.203
3	M/M/M	B	-0.05	0.017	-1.01	0.0	0.49	0.084	0.29	0.154
4	M/M/M	A	0.02	0.019	0.44	0.0	0.49	0.084	0.60	0.226
5	C/C	B	0.51	0.031	10.57	0.09	0.34	0.071	0.72	0.238
6	C/C	A	0.34	0.027	7.02	0.088	0.34	0.071	0.47	0.189
7	Y	B	0.19	0.023	2.75	0.03	0.53	0.088	0.29	0.154
8	Y	A	0.41	0.029	6.02	0.074	0.53	0.088	0.66	0.226
9	F+M	A	0.09	0.021	1.85	0.018	0.53	0.088	0.60	0.215
10	F+Y	B	0.31	0.026	4.49	0.053	0.55	0.089	0.66	0.226
11	F+Y	A	0.24	0.025	3.53	0.04	0.69	0.101	0.72	0.238
12	M+Y	B	0.17	0.023	2.46	0.026	0.55	0.089	0.72	0.238
13	M+Y	A	0.19	0.023	2.72	0.029	0.59	0.093	0.72	0.238
14	F+M+Y	B	0.26	0.025	3.87	0.045	0.5	0.085	0.5	0.195
15	F+M+Y	A	0.31	0.026	4.51	0.054	0.77	0.108	0.72	0.238
16	F+Y→M	B	0.29	0.026	2.47	0.026	0.61	0.094	0.72	0.238
17	F+Y→M	A	0.44	0.03	3.81	0.044	0.79	0.110	0.72	0.238
18	F→M→M	A	-0.01	0.019	-0.09	0.0	0.66	0.099	0.60	0.215
19	F+M→M	A	-0.0	0.019	-0.01	0.0	0.59	0.093	0.60	0.215
20	M+Y→M	B	0.04	0.02	0.34	0.0	0.59	0.093	0.29	0.154
21	M+Y→M	A	0.22	0.024	1.89	0.018	0.72	0.104	0.72	0.238
22	M+Y→C	B	0.27	0.025	2.33	0.024	0.76	0.107	0.72	0.238
23	M+Y→C	A	0.05	0.02	0.83	0.004	0.51	0.086	0.72	0.238
24	C+Y→C	B	0.22	0.024	1.90	0.019	0.34	0.071	0.72	0.238
25	C+Y→C	A	0.30	0.026	2.53	0.027	0.57	0.091	0.72	0.238

j →	CHARACTERIZATION		PRODUCTIVITY OF INCOME		RELATIVE PRODUCTIVITY		GENERAL PRODUCTIVITY	INDEX OF USE OF LAND
			3.5.3		3.5.4		3.5.5	3.6.1
p(j)→			0.5		0.5			
w(j)→			0.39		0.05			
i ↓			VALUE	EVALUATION	VALUE	EVALUATION	VALUE	VALUE
1	F	B	0.15	0.127	0.08	0.015	0.33	0.42
2	F	A	0.15	0.127	0.82	0.033	0.45	0.42
3	M/M/M	B	0.15	0.127	0.08	0.015	0.38	0.46
4	M/M/M	A	0.15	0.127	0.82	0.033	0.47	0.46
5	C/C	B	0.85	0.253	0.27	0.019	0.58	0.47
6	C/C	B	0.85	0.253	0.22	0.018	0.53	0.47
7	Y	B	0.15	0.127	0.12	0.016	0.39	0.5
8	Y	A	0.85	0.253	0.42	0.023	0.59	0.5
9	F+M	A	0.15	0.127	0.96	0.037	0.47	0.46
10	F+Y	B	0.85	0.253	0.48	0.025	0.59	0.5
11	F+Y	A	0.85	0.253	1.00	0.038	0.63	0.5
12	M+Y	B	0.15	0.127	0.70	0.03	0.48	0.5
13	M+Y	A	0.15	0.127	0.97	0.037	0.50	0.5
14	F+M+Y	B	0.50	0.195	0.5	0.025	0.50	0.82
15	F+M+Y	A	0.85	0.253	0.98	0.037	0.64	0.5
16	F+Y→M	B	0.85	0.253	0.9	0.035	0.62	0.59
17	F+Y→M	A	0.85	0.253	1.00	0.038	0.64	0.59
18	F→M→M	A	0.15	0.127	1.00	0.038	0.48	0.59
19	F+M→M	A	0.15	0.127	1.00	0.038	0.47	0.55
20	M+Y→M	B	0.15	0.127	0.46	0.024	0.40	0.59
21	M+Y→M	A	0.85	0.253	1.0	0.038	0.63	0.59
22	M+Y→C	B	0.85	0.253	1.0	0.038	0.64	0.59
23	M+Y→C	A	0.85	0.253	1.0	0.038	0.62	0.59
24	C+Y→C	B	0.85	0.253	1.0	0.038	0.60	0.59
25	C+Y→C	A	0.85	0.253	1.0	0.038	0.62	0.59

j → p(j) → w(j) → i ↓	CHARACTERIZATION		INDEX OF USE OF LABOR	INDEX OF PROFITABILITY	GENERAL INDEX OF USE OF RESOURCES	TRADEOFF INDEX OF FEASIBILITY
			3.6.2	3.6.3	3.6.4	3.7
			VALUE	VALUE	VALUE	VALUE
1	F	B	0.46	0.18	0.37	0.70
2	F	A	0.46	0.24	0.43	0.88
3	M/M/M	B	0.46	0.18	0.39	0.77
4	M/M/M	A	0.46	0.27	0.48	0.95
5	C/C	B	0.51	0.77	1.01	1.59
6	C/C	A	0.47	0.49	0.71	1.24
7	Y	B	0.46	0.34	0.57	0.96
8	Y	A	0.46	0.46	0.69	1.28
9	F+M	A	0.46	0.30	0.51	0.98
10	F+Y	B	0.48	0.45	0.69	1.28
11	F+Y	A	0.46	0.32	0.55	1.18
12	M+Y	B	0.46	0.34	0.57	1.05
13	M+Y	A	0.46	0.31	0.54	1.04
14	F+M+Y	B	0.5	0.5	0.91	1.41
15	F+M+Y	A	0.47	0.36	0.60	1.24
16	F+Y→M	B	0.5	0.42	0.72	1.34
17	F+Y→M	A	0.47	0.40	0.58	1.22
18	F→M→M	A	0.46	0.11	0.38	0.86
19	F+M→M	A	0.46	0.11	0.36	0.83
20	M+Y→M	B	0.48	0.26	0.54	0.94
21	M+Y→M	A	0.46	0.30	0.57	1.20
22	M+Y→C	B	0.48	0.31	0.59	1.23
23	M+Y→C	A	0.49	0.22	0.51	1.12
24	C+Y→C	B	0.52	0.29	0.60	1.20
25	C+Y→C	A	0.51	0.33	0.63	1.25

Foreign Assistance

Some Emerging Modes of Technology Exchange in the U.S. Foreign Assistance Program

HENRY ARNOLD*

I want to make one major point in this discussion, which is that the nature of the U.S. Foreign Assistance Program, particularly that part of it that has to do with technology exchange, is changing rapidly. In fact, the pace of change is accelerating as it is in every kind of technological development.

Let us begin by talking a bit about the history of the Foreign Assistance Program; things you may know, but let me remind you. The Program started some 30 years ago, after World War II, with something called the Marshall Plan. The major element of the Marshall Plan was a program of loans to countries in Europe to permit them to reconstruct their economies. That initial effort was so successful that the pattern of foreign assistance thus established tended to persist through

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the next 30 years, even though the needs and skills of the recipients of the program changed radically. Instead of dealing with people having highly sophisticated technical skills, as in the European countries 30 years ago, where only capital was needed to go ahead, we are now dealing with the poorest of the poor, the least educated people in the poorest countries in the world. That is one feature of the program that has changed.

After the Marshall Plan, the agency went through a number of metamorpheses. The programs were usually designed to provide capital, more or less like the Marshall Plan, to governments, in the hope that the benefits would "trickle down" to everybody along the way. Technical assistance was provided as an adjunct to the loans. That practice fell into disrepute because the benefits did not seem to "trickle down." Now we are focussing on the very poor countries, and on the poor segments of those poor countries, which, generally speaking, are in the rural areas. At the same time, technical assistance and technology exchange are becoming more important in their own right to build indigenous competence for solving future development problems.

There are three principal categories of foreign assistance provided by the U.S. government. One is called Development Assistance, and that is what I will talk mostly about. Of the two other kinds of programs, one is called Supporting Assistance, and the other Military Assistance. Development Assistance has been aimed primarily at reconstructing the economic structure, and lately, to some extent, developing the social structure of the recipient countries. Supporting Assistance is intended primarily to stabilize the situations in countries or regions where political or economic instability threatens regional peace. I think you are all familiar with the Military Assistance Program. We in AID are generally glad that during this past year our Agency was divorced from the Military and Supporting Assistance Programs by the Congress; they are programs that we did not have anything to do with, but often got criticized for.

To set the Development Assistance segment of the Foreign Assistance Program in perspective, funding for the fiscal year 1977 is approximately a billion dollars, which is a very small part of the total U.S. Government expenditures. In fact, as I was thinking about this, I realized that is just about what it costs to build one nuclear aircraft carrier. Together with the Supporting Assistance Program, it is less than 1% of the total U.S. Government budget. The total of my Office of Science and Technology is, in turn, less than 1% of the total Development Assistance Program, or to continue the comparison, about 1/3 to 1/4 of the quoted cost of an F-15 combat aircraft.

Recently, the Development Assistance Program has concentrated on several major and urgent world problems. I am sure you are familiar with them. They are given in this order of priority: first, food and nutrition; second: family planning and health; and third: education. The planned recipients of the AID program are the poor segments of those people who live in developing countries. Incidentally, projecting to

the year 2,000, about 4 out of every 5 people will be living in underdeveloped regions, so AID's bilateral programs cannot, of course, hope to reach all of them. The AID program is limited by Congress and by available funds to about 40 of the poorest countries, and it is aimed chiefly at the rural populations. The style of the program is collaborative, meaning that AID does not provide assistance except in collaboration with the governments of recipient countries. The countries themselves contribute resources, skills, and sometimes local money. They must always ask for specific assistance before it can be offered by AID. In turn, the U.S. is able to exercise whatever selectivity it considers advisable by accepting some of those requests and rejecting others. For example, if the request for assistance comes in an area which AID feels is not high enough in the priority of major problems, or if the environmental consequences seem unacceptable, we have to say: "Sorry, we can't help with that particular kind of thing." If some country wanted assistance to establish a national airline today, I think that would be the answer.

There are two major objectives of the Development Assistance Program: one is to help solve urgent problems like food shortage, overpopulation, or severe land erosion. Another is to help the developing countries build their own competence so they will need less help in the future. One is a short-range goal, and one is a long-range goal. Sometimes, there is conflict between attempts to achieve both objectives. Sometimes the choices are very difficult.

As I said at the beginning, the assistance program is changing. Why is it changing? Well, partly because the developing countries' interests are changing. They are now not only interested in solving extremely important and severe problems related to food, population, education, or health, but they are also placing importance on strengthening their own economic or political position in a world which is much more interdependent than ever. They want to strengthen their ability to interact with other nations in a manner which they feel is appropriate to their position as a sovereign nation, so that they do not have to be strongly dependent upon some other country. That interest in independence, in self-determination, is becoming stronger and stronger. In the speeches made in the recent United Nations General Assemblies, the UNCTAD Assembly in Nairobi, Kenya, and in the OAS Assembly at Santiago, Chile, one finds this theme repeated over and over again: "We want the ability to make our own choices. That is what we want in addition to, and as urgently as, assistance in getting more food or better health." The Charter of Economic Rights which was adopted a couple of years ago at the United Nations General Assembly is a very interesting document. It says, in effect, that the 120 or so developing countries of the world want to share equally in the science and technology and economic structure of the world. It says that if the basic economic system has to be changed to achieve this equity, then it has to be changed. There is a gap between the developed and the developing countries which is increasing rather than decreasing, despite the perhaps well-intentioned efforts of the developed countries.

So, in brief, what the developing countries are saying is that science and technology is the agent that made the western countries strong, that science and technology is what created the gap, and now they want quick and complete access to all the science and technology available, wherever it may have been generated, in order to close that gap.

The U.S. is trying to respond constructively to that point of view. Response is complicated because we have a system which has three different kinds of technology. One is technology in the public sector, that which is generated by the U.S. government or is not commercially oriented. Agricultural technology developed by USDA or space technology developed by NASA are examples. That is relatively easy to share. But the U.S. has other technology which is generated by the private sector for the purpose of making a profit for owners or stockholders. The U.S. government cannot give away that sort of technology, yet that is the very technology in which developing countries are most interested. In effect, they tell us: "The U.S. should change its system so that the government can direct that this proprietary technology be shared with us." Clearly that is a difficult if not impossible task for a country with our economic and social system, but the United States is trying to find a way or ways in which the objectives can be approached within the context of a continuing, vital, capitalistic system.

AID is trying to broaden the response to developing countries. We are trying to involve the private as well as the public sector in development assistance. We are trying to put more emphasis on using existing science and technology, rather than generating new knowledge in isolation of national needs, and in creating the necessary competence within the developing countries which will enable them to take this approach. We are trying to use what might be called "advanced" technologies as well as very simple technologies, and adapting them to conditions in developing countries. We are trying to devote a reasonable proportion of the effort toward the solution of very pressing problems, including those with adverse and possibly irreversible consequences such as environmental degradation, energy costs, desertification, and erosion, those problems that will not wait for years until competence is built-up in developing countries. The U.S. is recognizing also that it cannot drop its long-standing and often hard-won economic and technological relationships with countries now considered to be in the "middle income" category. We need to maintain association with them, we need to pull them into the world effort to assist the poorer countries, we need to benefit from the experience and skills that they have learned while moving from the "poor" up into the "middle income" area. Continued technology exchange with them on appropriate terms is one mode for maintaining such relationships.

We also know that one cannot develop a generalized response, suitable for every country. Not only do we need to deal with a spectrum of countries from poor to middle income, but we must recognize that

each country has a very specific set of conditions which differentiate it from its neighbors. Certainly, a country like Niger is so different from Nepal that one cannot even think about them in the same terms. Thus, our programs need to be tailored to specific countries. We need to understand that the problems are never simple, that they are never solely problems of growing more food, or problems of environment. Social, technical, economic, and cultural issues are inextricably interactive. A month or so ago, at a seminar in Nepal, I was impressed with this fact in a discussion of what the newly formed Council of Science and Technology of the Nepalese government should set as its priorities. We talked about all of the usual things, like agricultural problems, animal husbandry, forestry, and so on. Finally, after six days, the Nepalese participants decided that their most urgent problem was to develop a new energy source for the remote regions of Nepal. One of the reasons for their decision was that, as in many other countries with growing populations, enough food is no longer being grown, so they cut down trees to make more land available for agriculture. Because the trees are being cut down, the hills are being washed away in the monsoon season, reducing the land available for growing food. Furthermore, in most of Nepal, trees are the major source of energy, but the rate of cutting now exceeds the renewal rate. Here is the interactive mix: energy, food, environment, and erosion, and that is the way it seems to be coming out in almost every case.

Perhaps I could now recapitulate some of what I call the "emerging modes of technology exchange." First, there is an effort to get a greater involvement of non-governmental U.S. personnel into the program. For universities, 211(d) grants are one of the ways. Universities are also involved in the Title XII program for agriculture and food production. (Title XII is a new section of the current Foreign Assistance Act which establishes a strong, representative organization of Land Grant and Sea Grant universities to provide policy guidance and assistance to AID in utilizing the knowledge and resources of the United States related to the production of food and the problems of nutrition.)

A second involvement of non-governmental personnel draws upon the private, commercial sector. The last Foreign Assistance authorization act contains a section (107) which establishes a program of more effective utilization of so-called "appropriate technology" (technology aimed at rural areas and largely at using the available inexpensive labor while conserving the scarce capital) for food production and other activities of the rural sector. At the request of Congress, AID has established an organization called "Appropriate Technology International," with a distinguished Board of Directors from the private sector. It is expected to function somewhat like a foundation, receiving grants from AID which they will dispose for the purpose of promoting the use of appropriate technology in developing countries.

A second major thrust to involve private enterprise is called the International Industrialization Institute. We propose this be an

independent, non-governmental, non-profit research center with representatives not only from all interested nations, but from private enterprise. It will assist decision-makers in developing and developed countries to understand the broad process of industrialization across the world, and how the industrial decisions of one country might affect another country, as well as their own position, in international trade. The interaction I spoke of earlier is so intense in the industrial sector that no country can industrialize without affecting others and, in turn, being affected by them. Both developing and developed countries need to learn more about the process of industrialization in today's world because it is not anything like the process when the United States, England, or even Japan, industrialized.

The United Nations General Assembly has decided to have a world conference on science and technology in 1979, through which they would bring together representatives from member countries to examine how science and technology could help solve their development problems. The U.S. is making a major effort to respond in the most constructive way it can, and is involving the private sector in the response. To establish an integrated U.S. position which truly represents the private, academic, and public sectors, there was a preliminary meeting in Washington on November 17, 1976.

In the Foreign Assistance Act there is a section authorizing AID to facilitate Country Financed Programs, a reimbursable type of assistance intended to be responsive to countries which do not qualify for concessional assistance. Countries such as Korea, Taiwan, and Brazil, which are up on the scale of economy, can ask where to go in the United States to get a certain kind of technology, whether it be to the private sector or the public sector. To the extent which limited resources permit, AID attempts to act as the middle-man or broker in establishing that linkage.

There is increased emphasis on doing research in laboratories in the United States to solve the priority problems of developing countries. An example is a contract which our Office has with Monsanto Research Corporation to develop roofing material for developing countries that will be cheaper than corregated iron, that will not require foreign exchange because it will consist mostly of local materials, that can be built by local people, that will resist weather, corrosion and insects, and that will minimize casualties in the event of earthquakes. In short, this would be a better material at a cheaper cost. I expect it will soon produce an appropriate solution to a pressing problem that exists world-wide.

The U.S. is also seeking to involve developing country scientists by funding research in developing country laboratories where the competence exists to handle it. There are not many institutes in developing countries that can handle complex problems, but our objective is also to build up the scientific competence of the country, and to direct

it toward real life problems rather than strictly academic pursuits. In some cases, these institutes are linked together in what we call networks. There are six to eight such industrial research institutes around the world which not only exchange information about research, but may also exchange personnel, or provide training, or work collaboratively on a research program. The intent is to strengthen each through this collaborating network.

We are also trying to find ways to allow some of the middle income countries to work along with the U.S. in a three-party arrangement to help poorer countries. The middle income countries may have a better perspective on the problems than we do, while we may be able to offer some of the more sophisticated skills that they do not have.

The Agency has recently been making loans specifically for science and technology to countries such as Brazil and Korea, countries which have a scientific intrastructure of their own, and are capable of developing their own programs. These loans are made on the basis that the recipient country will decide what to do with the funds, and there will be very few strings attached.

Finally, a word about the application of more "advanced" technologies which can, but need not, be those on the "cutting edge" of new technologies. In our focus upon "appropriate" or "intermediate" technologies which have significant unrealized potential for developing countries, we often tend to overlook the potential of advanced technologies to improve the material well-being of the poor. In many cases, this may be attributed to a failure to recognize the technology's contribution; in others, to an unsubstantiated bias against its application on the part of peoples in developing countries. In its search for viable means to address critical problems of the disadvantaged, AID can ill afford to neglect these significant technologies because of developing country resistance or apathy. Advanced technologies not only offer a wider choice of approaches to specific development problems, but they hold the promise of "leap-frogging" some of the conventional, evolutionary steps in the development process, particularly in crucial fields such as energy, food production, health, and birth control. For example, it is possible to accelerate production of certain legumes as either food or energy sources by employing inexpensive plastic covers to advance and extend the growing season, a technique that eventually might offer rural areas new energy and food alternatives. The contribution of genetic research on high-yielding grains to food production in selected areas of the world, especially in heavily-populated Asia and the Near East, cannot be denied. When applied, these technological advantages can shorten by decades the time needed to guarantee the minimal life-support requirements of the poor majority.

In summary, then, U.S. Foreign Assistance is a living, changing, sometimes experimental, program. While directing its resources principally to alleviation of the critical needs of the poor, it must also react to the

changing patterns and legitimate political as well as economic aspirations of the developing world in our interests as well as theirs.

* * *

Discussion

Q. When foreign assistance comes from a highly developed country to a developing country, it is always somehow associated loosely or strongly with some political interest. Do you think that, instead of having national-level developing programs and assistance, it would be better to merge all of these programs into an internationally coordinated agency like the United Nations?

A. In concept I think that's right. Many people would agree with you. In fact, the United States would be delighted if it thought it could do this instead of having bilateral programs, but you must remember that those international agencies have their problems too; they are different kinds of problems, but they have problems. For example, the United Nations Industrial Development Organization, which you may be familiar with, feels the strain to be equitably responsive to all of its members. There are 120 members, so they take their money, which like everybody else's is, of course, not adequate to handle the job, and parcel it out to each of those members, and when they get through they don't have very much left to do what they think really ought to be done. There are problems of coordination, problems of making decisions which are divorced from the world political situation; you have a political situation there which is just as bad, really. So, I think my answer to that is one that derives from questions I have often asked developing country officials: "would you prefer to have United Nations programs or would you prefer to have bilateral programs?" Now, I am not so naive not to expect that they don't sometimes answer the way they think I would like them to, but I think that the reasons they give are pretty good reasons. Instead of a 10-year program, it takes 3 years bilaterally. So, there are some advantages and some disadvantages, and I would say that, at the present time, we probably need both kinds.

Q. Several weeks ago, maybe a month ago, I read an article in a local paper written by, I believe, the President of Texas Instruments, regarding transfer of advanced technology to third world countries, and his fear that it was going from third world countries to other developed countries which we didn't particularly want to send our advanced technology to. Are you familiar with this, and would you care to comment?

A. I would like to see the article. Well, I think that there is a legitimate concern from the viewpoint of a private company. As to how much technology goes to any other country, there is no difference whether it is advanced or not. If that company exists because of its skill and technology, then that becomes an important part of its continued existence, and naturally I am worried about it. I think, though, that most American companies, in high technology especially, face that same problem within the United States, and they have learned to live with it. They have learned, Texas Instruments has learned that the competition is going to be right in there if not ahead of them, and they have to keep chewing their heels on some new technology. So, I think they can learn to live with this problem. I am excluding military technology, which, of course, is in the realm of national security.

Q. You mentioned that Development Assistance spending is about one billion dollars for 1977. Do you happen to know how much Military Assistance is?

A. No I don't.

Q. In recognition of the world's finite resources, it seems like we in the United States can benefit world development by concentrating some of our resources on developing policies and industries to conserve the resources we are over-exporting. Does AID feel like it has a role in a system of this nature?

A. You mean on re-orienting U.S. industries? No, that is probably outside of AID's mission. But in a broader sense, I can see what you are saying. It might help developing countries, but I think AID probably would find that Congress would say this is not sufficiently direct assistance to developing countries to fall within its charter. We would rather have somebody else do that. We do it, however, in connection with the use of developing country resources, and, as you know, we have environmental programs in this country, EPA and the Council for Environmental Quality, which are really working hard on moving U.S. industries in that direction.

Q. The Technical Assistance Bureau, I would assume, is the agency that provides technical information, and one of the things that has come out in a lot of the literature, and I believe you effectively said it in some of the things you mentioned today, is that infrastructure and social awareness are probably as important in technology transfer, may be even more important, than pure technology. Now, where within AID do you plan for that sort of thing?

A. We don't. I'll give you a personal view, however; I don't think we have enough of that now. There is some of that within the Bureau for Program and Policy Coordination. Let's see, there is also some of it in our Bureau for Program and Management Services, but I think we are still lacking some of that. We have to make it up now by bringing in people from outside.

Q. That sort of raised a question that I have. It relates to your example of foreign assistance in regard to these programs. It seems to me that aid programs to developing countries have a problem in that even when there isn't the infrastructure to nourish whatever we do, or the contributions that we make, one has to address the fundamental question as to why those countries are in the state that they are. I mean, if you don't have energy resources, it is going to be very difficult no matter how much money you pump into the country.

A. That is what I was referring to when I said we had to balance between problem-solving and building up confidence within the country. We know that you can't transfer technology of any kind unless there is an understanding on both sides. We all know that the old saying: "Don't give people fish, teach them how to fish." That has some validity. So, a large part of OST programs, I would say myself two thirds of the programs, are directed to doing just that. Trying to help people build up the confidence to make their own choices of which technologies they want, and what the impact of adopting and adapting some of those technologies will be five or ten years from now. So, and the developing countries understand this very well, they say that this is what they want; they want the ability to make their own choices; that is what they mean by independence; they don't want us saying to them: "This is what will solve your problems." But some of the time spans to build up the confidence to where people can make those choices run up to 10 or 15 or 20 years, and maybe longer.

Q. Sometimes this must be quite frustrating because all the elements are not there, and I know that every developing country would like to be a Japan, for example; have no resources, and yet be one of the richest countries in the world.

A. Let me tell you an even more frustrating thing. I'll illustrate with an example from Colombia. About three years ago, we put together a team that could use a systems approach for solving some of Colombia's construction problems, some of its industrial problems. We lucked out and found 10 Colombians who not only were very interested in the problem, and very intelligent, but also happened to have gone to school in the United States. They talked the same language, they used an IBM 360 and everything else, so that there was a complete rapport between the U.S. team and this very competent team of Colombians. They worked together for a year, developed solutions to problems, and then we said: "OK, the whole thing has been done, and we have got the methodology; you know the answers, but we are going away, and will come back a year from now and see what has happened." And when we went back, we found only one of those ten fellows still working on the problem. The rest of them had been promoted to higher jobs in the country, and all

of the work they had done in developing that capacity was lost for that particular project. But it wasn't lost for the country, of course. So, it's frustrating because all kinds of things interrupt your programs.

Concluding Remarks

Some Retrospective Thoughts on Technology in Developing Countries

ROBERT L. BULFIN*

The preceding papers of this publication have dealt with a wide range of technology in developing countries. These papers have been grouped into an overview, low-level technology, high-level technology, and a discussion of the U.S. Foreign Assistance Program. The papers have addressed applications in agriculture, water and grain storage, industry, nuclear technology, and remote sensing; in addition, one paper discussed the criteria for technology selection. There are two areas of critical importance to developing countries which were not included: education and health. Although these areas may not be considered as strictly technological, there is certainly a technological component to each.

This paper will not attempt to summarize the preceding papers. Rather, it will attempt to emphasize certain points which seemed to recur throughout the preceding papers, even though they do represent a wide range of applications and levels of technology.

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The first such point concerns the effect of technology on development. It is obviously not always clear exactly how a change in technology will affect a given society. In some instances, certain types of technology may actually retard development. At the least, one must realize that technology is not a panacea; but given the right circumstances, along with the right technology, development may be encouraged.

Closely allied to the effect of technology is the social or cultural aspect of development. Technology does not exist in a vacuum, but must be viewed in the context of its social, cultural, and political environment. In many instances, the technological problem can be solved easily, but the solution may not be appropriate with respect to other factors. In most cases, selling the technology and making it palatable to the people who are to use it is more difficult than the technological solution.

Another recurring point, both in the papers and the discussions that followed their presentation, concerns the type of technology which should be used in developing countries. This point will again be discussed.

Ideally, technology should evolve from an attempt to attain some objective(s) by utilizing available resources while recognizing that certain restrictions or constraints exist. These are never constant, but vary from situation to situation, and it is the task of technological innovators to define these objectives, resources, and constraints, and apply their knowledge to create a technology for the particular situation.

In most industrialized countries, technology has evolved over the years in a manner similar to the creation of ideal technology. For example, in the Eighteenth Century, cheap labor was plentiful and mechanization was not fully developed, which led to the "sweat shop." As time went on, labor became more costly, and, relative to labor, capital became cheaper. This caused the development of technology which replaced labor with machines. This has resulted in highly specialized, capital-intensive, mass production of goods. Concurrent with the change in technology, industrialized countries evolved a supportive infrastructure, components of which include complicated marketing, transportation, and communication systems.

People who deal with technology on a daily basis usually do not sit down and re-define all of the objectives, resources, and constraints every time they face a problem. Their past experience allows them to take some facts for granted. However, as time passes, this may create problems. An example of this is the environmental problem which exists in the U.S. and other industrialized countries today. Pollution was not recognized as a constraint when only a few factories were dumping waste into a river. As more and more factories were built and the rivers were saturated with impurities, people realized that polluting technology is "bad." Thus, a constraint on new technology is that it does not increase the problem of pollution. This problem also arises in direct transfer of technology to developing countries. Most people would not question the ability to transport raw materials or finished goods to and from a factory in the

United States. But, in a developing country, this question may be critical. When technology transfer first started, people assumed that many objectives, resources, and constraints which are taken for granted in the developed countries are also applicable in developing countries. As earlier papers have pointed out, this is not the case, and the results of direct transfer were less than spectacular. This led to the birth of "intermediate technology."

Enough has been said in the previous papers about intermediate technology, but I would like to make two points. The first is that, over time, some practitioners of intermediate technology may have fallen into the same trap as the people who transferred technology directly. The basis of intermediate technology is a thematic framework, but many people have considered this framework to be inflexible. Thus, the objectives, resources, and constraints are assumed to be the same as the framework of intermediate technology. In many cases, the framework of intermediate technology is a very good approximation to the real objectives, resources, and constraints, but certainly not in all cases. We must fully investigate these considerations for every case individually, although the thematic framework of intermediate technology can be a good guideline for doing this.

The second point is that intermediate technology is an emotion-packed phrase. To its supporters it conjures up dreams of utopia, while its detractors immediately think of "second-class" technology. The phrase "appropriate technology" is slightly less emotional, but it is probably better to simply refer to "technology" in developing countries. This, then, assumes that the correct objectives, resources, and constraints are being considered.

As several of the papers point out, goals for a developing country are both extremely important and a subject of some disagreement. I will not list goals in this paper, but I do wish to note that there are few (if any) situations which have a single goal. Of the several goals which exist for a particular situation, a given technological solution might satisfy each goal to a different degree. Since some, if not all, of the goals will probably be in conflict, some type of trade-off is necessary. This further complicates matters, since now, not only do we need agreement on goals, but also on their relative importance. Unfortunately, this can only result from many hours of discussion and negotiation by the people involved.

I would now like to again define two aspects of technology, hardware and software. When most people think of technology, they form a mental picture of computers, automobiles, or large hydroelectric generators. I refer to this component of technology as hardware. Hardware is certainly important, and much of the effort of engineers and scientists has been in designing and improving hardware. However, there is another component of technology which may well be as important as hardware, but has been grossly neglected; this I call software. Software is the invisible component of technology, and may be considered in two categories. The

first is technical knowledge applied to a particular task, or what might be called specific knowledge. This type of software may express itself as the decision procedure used to determine when and what crops a farmer should plant, or the knowledge of a skilled maintenance mechanic. The other type of software is the technology of the people, and may be considered as technical know-how. This knowledge determines the level of technology that a people are able to assimilate.

If we examine the previous papers in light of the hardware versus software aspect, we find that only Wymore's was truly concerned with software, although certain aspects of Berry's paper were strongly related to software. All papers dealt with software to some extent, of course, but it was not the main thrust of most of them. As I mentioned previously, this aspect, in my opinion, has been grossly neglected, and is an area that should be more fully exploited in the future.

It is interesting to note that the software aspect of technology was more prevalent in high technology examples. This may be a very appropriate application for developing countries. Usually, software does not require large amounts of capital investments, nor is it expensive to maintain, and it usually does not require skilled people for its implementation. Also, there may be a sufficient number of people in a given country who were educated in industrialized countries to carry out sophisticated software technology projects locally. As an example, during a recent conversation with an Assistant Director in the Ministry of the Environment of Upper Volta, it was mentioned that the timing of crop planting is very critical. If seed is planted at the first rain, and then the rainy season does not start, the seed is lost. Last year, some farmers planted five or six times because of "false starts" of the rainy season. On the other hand, if the farmer delays his decision to plant too long, he does not have the benefit of the full growing season. If sophisticated techniques could be used to determine a decision rule that could be easily implemented (e.g., plant after one millimeter of rain has fallen), then much relief could be provided to the farmer. It would require very little capital, give great returns, and, if all the social aspects were considered, the farmers might even be convinced to use it.

The final thought of this paper concerns the difficulty of development. The industrialized countries required several hundred years to reach their stage of development. It should not take the developing countries as long to reach the same stage, but it cannot happen overnight. It is true that the developing countries will receive help from the developed countries, probably at an increased rate, which should speed up their development process.

However, the world is beginning to realize that natural resources are scarce, and increasing prices will make it more difficult for many of the developing countries to obtain them. Added to this will be large increases in population, and conflicts in developmental goals. The result will surely be one of the most challenging problems facing mankind today.

* * *

Discussion

Q. After your last comment, I get the feeling you have no hope for developing countries.

A. No, I'm not implying that it's hopeless at all. As a matter of fact, I think that's really the saving grace. It's such a tough problem that you know it's challenging, and people are going to work harder. I don't think there is an easy solution. But it is certainly not hopeless. It's not something that's going to be solved tomorrow.

Q. Even though everyone admitted the social aspect is important, very few of the speakers actually addressed the problem of how to handle it. Could you explain that?

A. First of all, when you only have 45 minutes to say something to really cover the social aspects, you can't do it. I really think that is why people did not talk about it extensively. I think that all speakers realized that the social problems are there, and that they are just as large as any technical problems.

Q. I thought your example of when to plant was a good example of mixing high-level and low-level technology.

A. The real key is objectives, and, if you look at some of the objectives of U.S. technology versus some of the objectives of developing country technology, as I pointed out in the first seminar, those may, in fact, be diametrically opposed. You develop the technology given the objectives, but somebody has to come up with the objectives, and the obvious person to do that is the person that needs the technology, or is going to use the technology. In the example you mention, there is a farmer who says "this is what I want" and the result is an example of good technology.

Q. Except why do we worry about such a problem since it has been solved some 1,000 years ago by the Mayans. Their priests had a role in society precisely because they were able to predict the onset of the rains. They also distributed this information to the users, in this case the Mayan farmers. Thus, technology transfer is an idea that has been around a long, long time.

A. Yes, but unfortunately most of the technology transfer capability of the Mayan priests died with their culture, as did that of the Egyptians and other cultures.

Q. Being an engineer, I can't conceive of labor-intensive methods being competitive with mechanized methods. Can you justify your statement to that effect?

A. I think there are two things that we have got to consider here. It comes back to the objectives. Maybe the objective is not to maximize

profit, but to increase employment, and maybe the government would like to subsidize to some degree this particular outfit that is doing the manufacturing. In a word, to have people working. Secondly, when you say that you can't conceive of a labor-intensive manufacturing operation being competitive with a mechanized operation, I think you are considering the present technology for labor intensive manufacture. Now, as an industrial engineer, I can say that we have done a very poor job of coming up with efficient labor intensive manufacturing techniques. The reason comes back to the same thing that I mentioned in my paper. If you look at what is going on in the U.S. today, capital is cheap, labor is expensive. What do we do? We mechanize, so all of our efforts have been in building good technology for the assembly line. Nobody has looked at building good technology for labor intensive things, except, with the possible exception of China. I don't really know everything that is going on in China, but I do know they are doing some very creative things from a manufacturing standpoint with labor intensive manufacture. I don't know if it can be done, though I have a suspicion that you can, in fact, develop labor intensive manufacturing methods that, under the conditions of cheaper labor or more expensive capital, are competitive with highly mechanized manufacturing methods.

Q. I would like to propose the idea that maybe the problem is that perhaps we don't understand the problem. And that what we try to do is to sort of transplant ideas and concepts; we see that they are efficient in one area in the world, and we try somehow to transplant them. It is like taking a tree from up on Mount Lemmon and taking it down and putting it in your front yard; it won't last very long. We have to consider the environment to which the technology is transplanted and that includes the political system and the resources of the country. I think all of you can see, for example, that we really don't have to worry about further development of Saudi Arabia, and Libya. In fact, Libya just bought 12% of Fiat. The Chinese, I think, would never have developed if they had continued with the same political system they had before, no matter how much aid the government gave to China.

A. That is exactly what I meant when I said that when you transfer technology you must quit looking at things, as you say, piece-meal, and start looking at things from a little larger perspective.

Q. Do you think that technology can solve the development problem?

A. Technology alone can't, but it can certainly help if used in the proper way.