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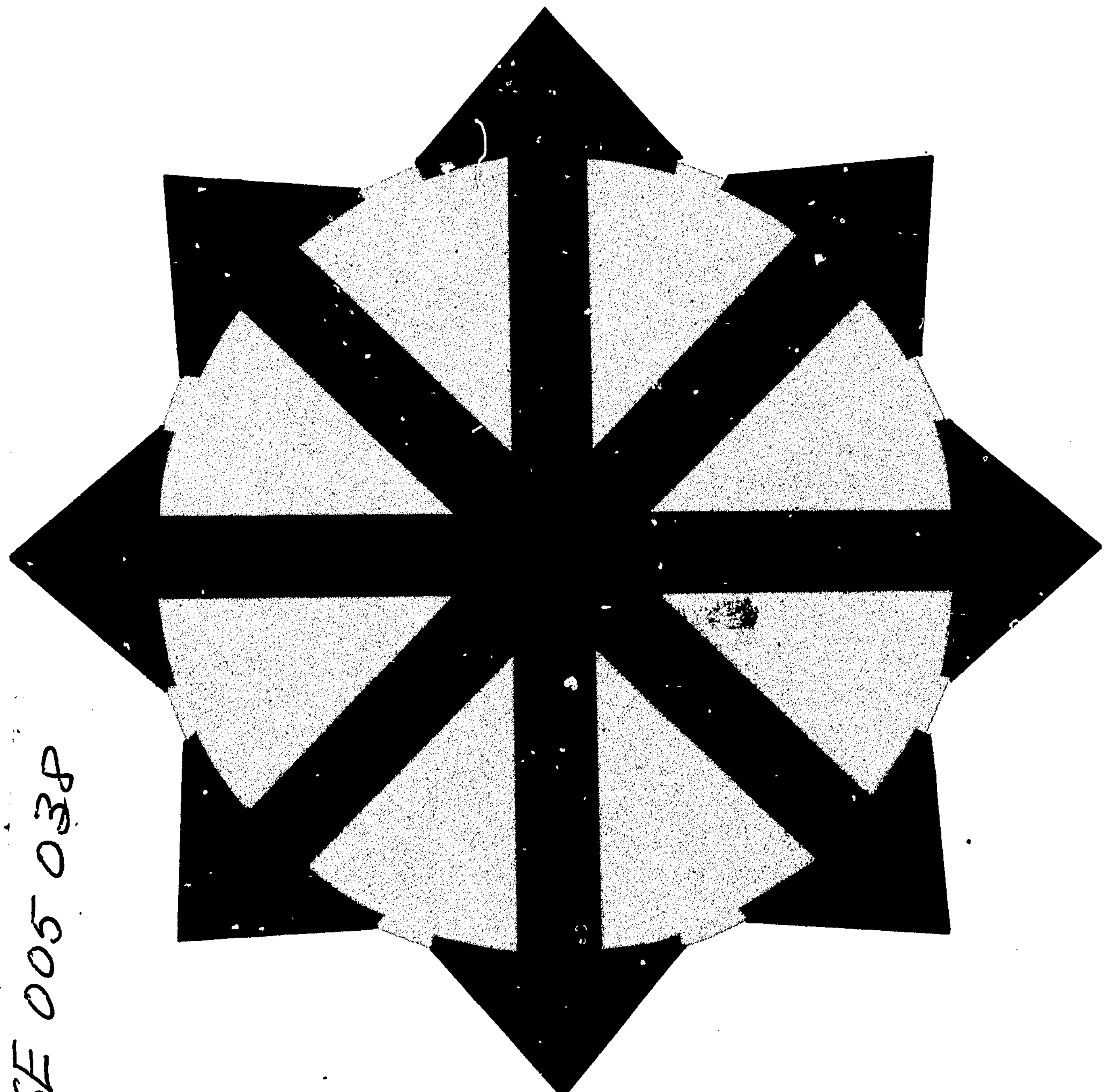
Reported are speeches presented at a Summer Engineering Symposium which deals with the general theme "Man in Contemporary Society." A historical perspective of engineering leading to its future role in society was established. From this base other papers applied engineering concepts to socioeconomic systems, educational systems, simulation in medicine and pollution control. Recurrent themes included enlarging the concept of the profession's role in society, applying the engineering systems approach to human systems, and identifying the engineering profession's future contribution to society. (GR)

ENGINEERING: A LOOK INWARD AND A REACH OUTWARD

PROCEEDINGS OF THE SUMMER SPEAKER SERIES



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EDITED BY:
Arnold Reisman

Summer 1967

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CONTENTS

speakers

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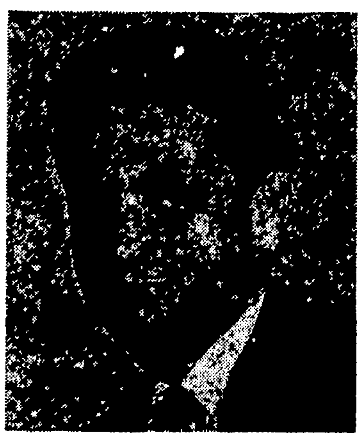

FREDERICK C. LINDVALL

. . . is chairman of the Division of Engineering and Applied Science, California Institute of Technology, Pasadena, California. He received his B.S. in Railway Engineering from the University of Illinois, and his Ph.D. in Electrical Engineering from the California Institute of Technology. Dr. Lindvall holds honorary Doctorates from Purdue and the National University of Ireland, as well as the Naval Ordnance Development Award, the Presidential Citation for Merit and the Lamme Medal. He is presently on over fifteen consulting and advisory committees and on the board of directors for many companies such as Bell and Howell, Bank of America, Independence Life Insurance, Northcote, Stanford Research Institute, and several others. His society affiliations include a fellow of the Institute of Electrical and Electronic Engineers, past president of A.S.E.E., president-elect of Sigma Xi and an active member in the National Academy of Engineering, the African Science board of the National Academy of Science, the Engineering Council for Professional Development as well as over thirteen other organizations. He is a Registered Professional Engineer in California.

GERALD NADLER

. . . Professor Mechanical Engineering (Chairman, Industrial Engineering Division) the University of Wisconsin, received the Ph.D. degree from Purdue University and joined the faculty of Washington University, St. Louis. During 15 years of teaching, he became Professor of Engineering and Chairman of the Human and Organization Factors Area. In 1964 he came to Wisconsin. He has written widely about research, industrial and consulting activities, is the author of three books including the most recent, "The Ideals Concept." Dr. Nadler has lectured at many universities here and abroad. In 1959 he was Visiting Professor at the University of Birmingham, England, and in 1963-64 at Waseda University, Tokyo. He is consultant to Southwestern Bell Telephone Company, Decatur and Macon County Hospital, St. Louis Car Company, Monsanto Chemical Company and others. In 1961 he was honored as Gilbreth Medalist by The Society for Advancement of Management.

MARTIN I. TAFT

. . . is a Visiting Associate of Engineering and Education at The University of Wisconsin at Milwaukee. He received the degrees of B.A. in philosophy from Brooklyn College in 1952, B.M.E. at the Polytechnic Institute of Brooklyn in 1956, General Secondary Credential from the University of Southern California in 1958, and M.S.M.E. in 1960 and Ph.D. in Engineering in 1966, both from the University of Southern California. Professor Taft is presently interested in the application of systems analysis techniques to socio-economic systems in general and to education problems in particular. He has presented and published several papers both in this country and abroad in the areas of education, energetics, and management science, and has authored several technical reports. He is now coauthoring, with Arnold Reisman, the book *Design for Education: A Systems Approach* which will be published by the University of California Press.

STEPHEN ABRAHAMSON

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GAYLORD NELSON

. . . United States Senator from the State of Wisconsin, graduated from San Jose State College in California in 1939, and received his law degree from The University of Wisconsin in 1942. He was an officer in the U.S. Army for 46 months during World War II, serving in the Okinawa campaign. Nelson began pacticing law in Madison in 1946. In 1948, he was elected State Senator from Dane County. He was re-elected in 1952 and 1956. He was elected governor in 1958, and re-elected in 1960, becoming the only Democrat to win two terms as governor of Wisconsin since 1892. Governor Nelson in 1962 successfully sought election to the United States Senate.

We are indebted to Dr. C. L. Golightly, Assistant to the Chancellor, and Director of our Summer Session, for the encouragement and support for this program which represents an enrichment of our summer session offerings. The general theme of the Summer Session special program was Man in Contemporary Society, *involving the College of Letters and Science as well as the College of Applied Science & Engineering and a number of local technical societies. The title, "Engineering: A Look Inward and a Reach Outward" fits the general theme of* Man in Contemporary Society.

With the profession of engineering taking an increasingly greater responsibility in social, economic and urban affairs in addition to its traditional interest in technological problems, it is important for us that our new College of Applied Science & Engineering plan its curriculum to meet this need. Therefore we are most grateful to have had the opportunity to listen to and to read the comments of the speakers whose papers are included herein. The challenges they present to us as educators and engineers remain before us.

PHILIP C. ROSENTHAL

University of Wisconsin-Milwaukee
Dean, College of Applied Science and Engineering

introduction

Much has been, is being and will continue to be said and written about the profession of engineering. Our large scale space and defense efforts have both enhanced as well as detracted from the lay public's understanding of what this profession entails. While the engineering profession shapes into reality the dreams and discoveries of the sciences our mass media of communication have over the last few years, by and large performed a disservice to the profession. Thus, space effort successes were and still are hailed as "scientific achievements," and the dramatic setbacks are dubbed "engineering failures." The public in general and the youth in particular, are confused or misinformed regarding the role engineering plays in our economy as well as in our daily lives. More serious, however, is the division of views within the engineering profession itself regarding the role this profession ought to assume and particularly regarding the best preparation in terms of education for this role. We have on the one hand those who insist on a highly specialized education rich in the arts and crafts of that particular specialty. We have others on the other hand who argue that the engineering arts are subject to rapid change and/or replacement because of advances in technology. They point to the many engineering specialties which have vanished over the last two decades and argue that the best preparation for the engineer of tomorrow ought to primarily stress an understanding of the basic scientific laws and engineering principles. They argue that this broad and basic education will produce a professional who is flexible in moving from one specialty to another and is in a better position to tackle problems which were either nonexistent or even undreamed of during the time of his preparation for the profession. However, this kind of preparation in many instances, places a man at a disadvantage during the early part of his career, for he has not the skills necessary to "earn his keep" so to speak. Thus the debate rages. There are some other aspects of the practice engineering which are not widely known outside as well as within the profession. It is not generally known that an ever increasing fraction of the profession is extending its areas of operation from the hardware or "nuts and bolts" aspects of industry to the planning, design, management and control systems which are: purely socio-economic in nature; purely physiological or biological in nature; and others which represent a combination of the above two as well as physical aspects. Thus, we now find engineers in medicine, health care institutions, banking, municipal, state and federal government, social welfare agencies, information or data centers, commerce, military planning, oceanography, environmental control, etc. We find engineers working with economists, sociologists, meteorologists, biologists, psychologists, physiologists, medical doctors, business managers as well as with the more *traditionally allied professionals namely, chemists, mathematicians and physicists. We find interdisciplinary teams of engineers and professionals in these other disciplines more and more frequently though not as yet commonplace. Thus the engineer is becoming acquainted with both the problems and the language of these other disciplines. In turn practitioners in many disciplines are now coming to the realization that tools developed and used by engineers can and do impact their own operations. Thus, bridges between professions are being established or conversely, the barriers are being broken down.*

It is also not generally recognized that more and more engineers are being callend upon as integrators of the functions peformed by the specialists. Because of the ever increasing complexity of projects handled by engineers there is an ever increasing demand for generalists as opposed to specialists. We have in mind those who understand the problems of the various specialties involved in a project and who know how to combine the outputs of the specialties in such a manner that the total project is optimized. We have in mind those who can see the total picture. It is now a well established fact that in general, the best designed components in combination, do not make for the best designed total project.

With the above thoughts in mind the faculty of the College of Applied Science and Engineering at the University of Wisconsin—Milwaukee has chosen as its 1967 Summer Symposium subject the theme "Engineering: A Look Inward and a Reach Outward." For the "Look Inward" we have asked one of the most distinguished members of the engineering profession to share his thoughts with us. He is Professor Frederick C. Lindvall, Chairman, since 1942, of the Division of Applied Science and Engineering at the California Institute of Technology. To discuss the "Reach Outward," we invited men who are currently pioneering in their respective areas and who can show concrete results as part of their accomplishment. Not all of these men are engineers by training, yet their work has brought them in close contact with engineers through active collaboration.

ARNOLD REISMAN

Visiting Professor of Engineering

ENGINEERING: ITS PAST, ITS PRESENT AND ITS FUTURE

Dr. Frederick C. Lindvall

Chairman, Division of Applied Science and Engineering
The California Institute of Technology

Thank you very much Dean Rosenthal, and may I say, fellow students, I am sincere in saying fellow students, because in talking about this kind of a subject, nobody has the answers. We are all trying to explore these things together. Arnold Reisman, in his introduction of my talk promised "the best thinking on this subject," all you can hope for, of course, is my best thinking—take it at that. I would like to take a little bit of a look inward before trying to look outward, and review very briefly the general history of engineering. Through the decades things have happened in the thought and the practice of engineering which have gone in differing directions and in which we seem to be coming together again with the scientists. If we go back far enough, there are many developments which you would now consider engineering inventions or ideas, but which were generated without regard to utility. Some of these were nice gadgets so that the priests could impress the people in the temple with the fact that the doors would open and close mysteriously. Hydraulic means were of course employed. There were organs that played music employing water effects, and other things of that sort. These were really interesting inventions, but they had no object of cutting down the labor or improving the welfare of man. It should be recognized, after all, that these developments took place when the whole economy was based on slave labor. Then we come to the period in which we witnessed the rise of the military engineers. Military engineers did many things other than those which were strictly military in nature. They were involved, of course, in public works, as represented by the Roman roads and aqueducts, and the sewer system which dumped the sewage of Rome into the Tiber River. This practice is not much different from what goes on today in many American cities. Then we come to the age of mechanical power and industrialization. Engineering, as we think of it today, began to emerge, and it separated from what was called in those times "natural philosophy." It is historically a fact that there has always been an intimate association between engineering and science. Some of these early engineers made basic contributions to science. Just some simple examples: Coulomb, educated as a military engineer, developed the first correct theory of retaining walls, and for his work on friction and rigidity of materials he obtained election to the French Academy of Sciences. As a member of the Academy, he became interested in problems of electricity, with which we normally associate his name, but he did a great deal of work in basic mechanics before he became identified as a scientist in electricity and magnetism. Sadi Carnot, another military engineer, established the first principles of heat engines from which subsequent derivation produced the second law of thermodynamics. Then there was Count Rumford, who was interested in the machining of cannons for military objectives. This led him to a determination of the mechanical equivalent of heat. He didn't get quite the right answer, but nevertheless he performed some rather significant experiments in this direction. I might remark that an English physics textbook had a footnote stating that Count Rumford was born William Thomson in the American Colonies and was forced to flee from the Colonies because of his loyalty to the crown. My own history book on the other hand said he was a Tory! Watt was associated with the steam engine in our thinking, but he also tried to get into the more scientific aspects of things and did some of the first work to establish a value for the latent heat of vaporization of water. Joseph Henry was an American, an inventor trying to develop a communications system similar to the telegraph, and who stumbled onto a phenomenon which we now call the principle of electromagnetic induction. However, he was slow to get into print with this discovery, and so Faraday got the credit for what was a simultaneous discovery. Coming down to more recent times, Karl Jansky, an engineer at the Bell Laboratories working on transoceanic radio communication found "some curious stuff" coming from outer space, this stuff we now identify with radio astronomy. It took a long time before people recognized it for what it was. On the other hand, there are scientists who made very significant engineering contributions, if I may go on with a little name-dropping. In this Natural-Philosopher group we find the names of Kelvin, Maxwell, Lamb and Love. Earlier ones were Galileo, Castigliano, Bernoulli—all those names appear in our textbooks in mechanics and electricity, today the working ground of engineers. Lord Rumford, who was one of the first to explore atomic structure and the nucleus, stated in a lecture to the Royal Society that scientists should be very much concerned with the application of their work for the benefit of man. This is precisely the same objective that engineers have or ought to have.

If we look a bit at the education which scientists have had in relatively recent times, we find that the Ph.D. is definitely the union card. There are very few people who are seriously in science but who have not gone on to the doctorate. These people it turned out had fairly broad education. Their knowledge was adaptable and transferable. Engineering education, on the other hand, had been focused primarily on the four-year Bachelor's degree. In the early 1930's there were few people who had earned Engineering Ph.D. degrees. Engineering education tended to be more specialized. In those years the state of the art in engineering did not change very rapidly, and therefore, teachers with practical experience didn't find themselves becoming obsolete in a few years. Rapid obsolescence of people who have specialized in some particular engineering art is likely to happen today. As technology then moved more slowly, there was a longer period between discovery and application. Know-how lasted for a longer time. Engineering education was more applied and practical. In terms of the people and their education, a survey by the National Science Foundation a few years ago revealed the fact that a very significant fraction, 15 - 20% of those identified as engineers, had no education beyond high school. There is nothing wrong with this but this was not true in the sciences. World War II put many scientists into war work of a type which we could call engineering. Many of them did exceedingly good work, demonstrating very clearly the merit of the breadth of advanced education and the merit of the research experience in attacking new problems. The ability to apply basic principles to new situations led many of these scientists to make great contributions. Those who made the best contributions were clearly the elite of the science world, and today they constitute a large segment of what some people call "the establishment" with respect to governmental advising and science policy. But, for the most part they were very smart people; they were uninhibited by engineering art and practice and looked at problems from the fundamental point of view. In other words, they started from scratch and attacked problems from the research point of view. Also some of these scientists were really very practical fellows when it came right down to it, as I learned from working with physicists developing rockets for the Navy during the war. I was much impressed with the way they could do what I call good engineering design and improvising when we couldn't get the materials, shapes or processing that we wanted. Aeronautics is in a little different category. This field, since World War I, has enjoyed strong impetus from the military. Considerable effort went into aircraft development. Also there were people who saw that this was a coming field and one in which cut-and-try methods were not satisfactory. There was no lore or experience to draw upon in proceeding to advanced design in aircraft. During this period the fundamentals of modern fluid mechanics as applied to aircraft were established. However, what was developed to satisfy the needs of the aircraft designers found many applications in areas totally unrelated to aircraft. Thus, modern electricity producing power plants, modern and future automobiles have and will benefit from this knowledge. Designers of skyscrapers and of major bridges have and are using methods developed for the analysis and testing of aircraft models from the aerodynamic point of view. Indeed, this work anticipated some of the problems of transonic and supersonic flight.

Of recent years, science and engineering are once again coming closer in many areas. In other words, we were together, we spread apart; now, in many areas, we are coming back quite close together. Dr. William Baker, of the Bell Labs, has written a very interesting article which has the title, "Science and Engineering: A Sum, Not a Difference." There is a good deal of merit and substance in that little title. I don't need to enumerate some of the fields in which work in physics and work in engineering is almost indistinguishable.

Today, engineering education has expanded in scope to include a substantial amount of humanities and social sciences. This was talked about for many years and was incorporated into curricula at some schools in substantial amounts as long ago as 40-45 years. Technical subject matter has changed drastically since the last war. The level of work has risen. Graduate study has become a major activity in engineering schools, and there is continual self-evaluation. I know of no profession that is more self-conscious in evaluating their own work than that comprising engineering educators. The most recent activity is represented by the so-called "Goals Study." The Goals of Engineering Education Report it not uniformly nor warmly endorsed, but nevertheless it has merit and influence. Engineering as a whole has some weaknesses nationally and professionally. There is a serious lack of unity in the profession. We have the tradition of older professional engineering societies in which the emphasis is on the adjective—the kind of engineering—civil or chemical instead of it being Engineering. The medical profession does not do it quite this way. A doctor is an M.D. first, then he is identified as a specialist in orthopedics or psychiatry, or whatever. The specialty comes later. Also the engineering profession does not have a powerful organization such as AMA to speak for the profession.

There has been difficulty as a result of this compartmentalization in that certain new fields just simply wouldn't accommodate to the existing structure. Jet propulsion is one application which cuts across a wide spectrum of engineering activities. There was no place for it in any established professional society, so jet propulsion people went their own way. Now they have merged with the aero people in a joint society. There is a new field we heard discussed at a recent meeting of the American Society for Engineering Education; this field is ocean engineering. Now what is that exactly? Nobody is quite sure, but none of the professional societies is quite the right place to put it, so there will probably be a new society of ocean engineers. The members of this new society will not be oceanographers, they will not be geologists; they will be a new engineering specialty. Perhaps this splintering is partly the reason for the lack of public image about which engineers complain. Who cares about the public image of engineering except we in a personal way? However, there is a factor about which I think we are all a bit concerned. We think it has something to do with student career choices. Engineering is not understood well by the public, by the high school student, nor by the counselor. It is not understood by some of the other professions. What do the numbers look like? In 1958, of the male college population in the U.S., 23% chose engineering. In 1965 that fraction was down to 13½%. If we look at a different set of students, the male semifinalists in the National Merit Scholarship competition, we find that in 1957, 33% of these male semifinalists chose engineering or stated an engineering preference. In 1965, this group was down to 20%. In absolute numbers there is little change, but certainly no gain. We need a gain.

Arnold Toynbee, from his vantage point as a historian, has been trying to look at society in various ways, and he has come to the conclusion that in the U.S. and western Europe, young people are a bit saturated with technology. They have it all around them, and they are beginning to react a little, not against technology, but they are becoming unenthusiastic about getting into a professional activity that would continue to expand technology. Toynbee didn't say this, but some youth may say, "Who wants more TV sets, who wants more automobiles, who wants more air conditioning?" Is it something for a life-time career? And so some of these young people, Toynbee feels, are sensing that there may be something more important than just bolstering up technology. They are beginning to look into some of the social problems which technology may have created and is not solving. He may have a point, and this may have something to do with the general decline of interest in science and engineering careers.

In engineering I note two principal divergent trends: one is the trend toward narrower and narrower specialization, such as ocean engineering, or bio-engineering to name another one; and at the same time there is more and more interdisciplinary work being developed needing breadth. Bio-engineering can be interdisciplinary and can be very fruitful, or it can be extremely narrow and specialized, being almost nothing but instrumentation. For bio-engineering to be truly interdisciplinary, the engineer must learn a lot about physiology. He must talk the language of physiology and understand what the experiment or the measurement means. He can't be there simply as a supergrade technical aid. Thus bio-engineering is something that can go the right way or it can evolve into a narrow specialization. There is a further need for some very broad-gauge engineers. Nobody has invented a name for these fellows, but I think you will see what I mean as we go on. Now I want to drop back again in history a little over 200 years ago—to establish a framework for the place of engineers in the future. David Hume, one of the most influential British philosophers, stated, "Politics considers men as united in society and dependent upon each other." Hume saw men united in common purposes and objectives, undertaking projects too large or affecting too many to get done by a few. As he wrote in a treatise on Human Nature in 1740: "It is very difficult and indeed impossible for a thousand persons to agree on any such action, it being difficult for them to concert so complicated a design and still more difficult for them to execute it; while each seeks a pretext to free himself of the trouble and expense and would lay the whole burden on others. Political society easily remedies both these inconveniences. Thus, bridges are built; harbors are opened; ramparts are raised; canals formed; fleets equipped; armies disciplined." Hume could scarcely have seen the impact of technology in uniting men in society and increasing their interdependence. Transportation and communication have shrunk the world. Mass media of press, radio and television keep us continually, if not well, informed. Industries differ widely in product and size and are so closely intermeshed in the complex economy, that a change of pace in one quickly affects all. We are all, whether we like it or not, in Hume's words, "united in society and dependent on each other." Now, in considering these things that society needs to do as a whole, such as to build the bridges, to build the canals, and so on, to use Hume's examples, who does the planning, which the engineers will then execute?

Planning has been rather haphazard. We are beginning to see more of what is now called "systems engineering" applied to some of these things. This is a procedure used heavily in military planning but it is not a brand new idea by any means. We have had systems engineering in the electric utility business and in the telephone business for quite a long time with very sophisticated planning, organization and so on. Systems engineering is good and very powerful, but some distortion has come in. There has developed a kind of cult of systems engineering, a mystique, that somehow we can turn over social and technical problems to the good doctors and solution will result. There is a great deal of talk about applications to civil systems such as transport, water supply, pollution, waste management, urban development, hospitals and total problem of patient care. But when it comes to looking at systems-engineering applied to civil systems some skeptics believe that it will never occur until such time that a crisis exists, then engineers will be called in to provide a fix. I always remember one old consulting engineer who wished that sometime he would be called in at the planning phase rather than after the job got in trouble. Some people view systems engineering as a way of getting planning done without having it branded as socialistic, or in the name of this new science as a way to avoid unpopular political and social decisions by having someone else make them objectively. On the other hand, systems engineering is powerful, even though the concept is old professionally, and is more powerful today because new techniques of analysis and synthesis are available. One such technique is mathematical modeling. With the aid of mathematical modeling interactions of the various components of the systems can be studied in great detail. Such studies are greatly aided by modern computers and appropriate programs. However, there is real danger in trusting too much to the methods of systems engineering. The people who are doing systems work may not have a real understanding of the problem. If they don't understand the physics of the problem and have relevant background the study can be quite superficial. Some such superficial systems studies have taken place resulting in form without content. So I think we have to be a little careful lest systems engineering gets a bad name, because it can be formalism without having substance. Also one can restate the problem in a complex way without really synthesizing a sensible solution. However, in this field of systems engineering, which will grow, as it must, we will need specialists, of course, and we will need the system engineers—the broader gauge fellows who know when to call in the specialists, what specialists to call in and how to make use of them. There would be desirable educational differences between these people. A systems engineer, the top planner or the one who is guiding the study would not know all of the details in each phase or component. Hence, he must work with a large number of people, while the specialist can be as independent and as much of a prima donna as he pleases. The systems engineer can't play the prima donna role. He must work with a number of people, and the interpersonal relationships are very important. It takes a different personality and a different kind of educational background and approach to be a good systems engineer, I think. I am not sure how much systems engineering per se can be taught through any standard curriculum pattern. The pattern is now beginning to evolve and it may come, but we have to recognize that not everybody can do good systems engineering. The broad-gauge engineer must recognize what he doesn't know and be able to get the information. It calls for group effort, the resolution of conflicting requirements, and finding the best among several possible solutions.

I would like to give an example of a systems study that has had some success. A few years ago the Khan of Pakistan appealed to President Kennedy for help because the Indus River basin in West Pakistan, which had been in historic times a breadbasket of that part of the East, was rapidly losing agricultural land due to flooding and increasing salinity. How to stop this loss and recover the nonarable land was the problem. Through the President's Science Advisory Committee the problem was referred to a group at Harvard. There, a team of people was assembled to look at the whole problem; agriculturalists, economists, sociologists and engineers were involved in this truly interdisciplinary effort. The engineering part of it consisted of an analysis of a tube-well system which was proposed to pump some underground water to relieve flooding and flush out saline deposits. Where should these tube wells be? How many? What kind of pumping rates should be used? How would crop modifications change water demands? What should be the distribution of the pumped water? How much should be returned to the underground basin, and where? How much should be flushed into the river system out to sea to get rid of salts, and how fast would the salinity in the underground build up due to the fact that used water would be going back into the underground basin? Well, this was analyzed very carefully through models and a definite pattern of tube wells was designed for phase one of the project. A little over a year ago I was visiting in West Pakistan and I inquired about the success of the scheme. It was stated that the first phase was completed and that it was considered highly successful, and all they needed was to generate a little more capital to expand the scheme. This represents a broad-scale systems approach.

Water management as a whole is a field which should be considered as a system. Only recently have people begun to look at water in terms of the way to use it. When we stop to analyze what we do with water we find that it is essentially a transport device, and even in nature this transport phenomenon goes on. Our river systems are transporting solids, sediments and dissolved salts which are a consequence of erosion or are introduced by man. All of the solids are in the process of being transported to the ultimate sink, the ocean. We use water as a transport vehicle to get rid of human wastes, industrial and agricultural wastes. Thermal pollution as waste heat from power stations is another burden for the water. Normally one doesn't think of heat as a pollutant, but it can be quite a factor in changing the ecology of water systems and ultimately of water quality. We have the examples of Lake Erie which is in bad shape from pollution, and Lake Michigan which is in somewhat better shape because of some regulation. The City of Milwaukee simply can't use water to transport out its solid wastes. Instead, we buy them in California and I put them on my lawn in the form of milorganite. The management of water-borne material for ultimate disposition of solids is an over-all systems problem to which engineers have not directed their attention because they haven't actually thought of water as a transport mechanism. Then the question arises, how much can we use and reuse water, recharging depleting underground basins, etc.? What concern should we have for the buildup of salts? We are adding something to the water every time we use it and we keep building up the solid content as dissolved solids. There are mixing and dispersion problems, density currents and layers. There is the question of how one designs proper outfall sewers in the ocean. For years and years a big pipe with a simple open end has been used to dump effluent out to sea. There would be a plume of low density water, which was practically pure water, rising in the higher density sea water causing noticeable contamination on the surface. Finally, an engineer showed that the way to do this was to have a manifold system to give dispersion in a much larger volume of the ocean. This works well and quick dispersion is obtained with a density difference very slightly different from that of sea water. The thermal gradients of the sea water with the warmer water near the top established a kind of ceiling which contains this somewhat polluted sea water below the surface. Thus in the sea, thermal inversion is working for us just as it is working against us in the atmosphere in our miserable smog problem in Southern California. There are stratification problems behind dams giving rise to the problem of management of water of different qualities. There are questions of how much thermal pollution we can stand in given areas. Some rivers can handle only a limited amount of thermal waste because the water temperature rises too much and there are ecological changes which alter the character of the river. Even the nuclear power plants, which, are good from an air pollution standpoint, discharge as much heat as any other form of thermal power plant. This has to be taken care of, and you can't overload the streams with too much of this kind of pollution. I think it was Kenneth Boulding, the economist, who said, "The growth of affluence may be limited by the growth of effluence." The engineer takes a big part in these social and political problems but he can't handle them alone. These problems are interdisciplinary in nature and this again reflects in the kind of training the engineer should have.

Now a word about the engineer's responsibility to society. Is he to be a hired hand or a decision maker? I would like to quote a man of whom many of you have read already, Douglas Brown, the economist, and Dean of the faculty at Princeton. At the dedication of a new engineering building at Princeton, he said; "To perform this function in the implemetation of the vastly expanding science in an anxious world, the engineering profession must enlarge its concept of its role. It must throw aside the last vestiges of its evolution from a craft and take on the full responsibilities of a learned profession. The central attribute of a learned profession is responsibility, not for a segmented detail of the problem, but for an effective solution of the total problem. This means that for the profession of engineering, the days are past when each specialist can withdraw into his speciality and become a servant of someone else's grand design. Rather, the professional engineer must assume the initiative in helping to solve problems which in the past have been shrugged off as political, economic, social or as headaches for business or government. Instead of letting others come to him to design new patches on old garments, the professional engineer should help bring to bear the discoveries of science to design new garments, new approaches, and new solutions," and Brown continues, "The profession of engineering must seize the initiative in acting as a bridge between science and human needs. The scientist is not asked to apply his findings through design. The businessman or politician does not know what science offers or how to apply it. The engineering profession is a channel by which science can greatly improve our way of life, providing it assumes the initiative of leadership rather than the passive role of the hired consultant." That's a pretty stiff charge, and it has many implications for the future. As Brown says, the engineer should build a bridge between science and society's needs. He said a bridge—not walking on water. This may suggest a certain lack of divinity and it should because, after all, engineers are just people and they have human limitations. No matter how hard we as engineers try to judge between long and short-range solutions, we are somtimes forced into expedient compromises, the easiest path, rather than to go to the route to a more desirable long range solution. There are always economic factors. Somebody needs a quick cheap fix for some crisis. There are political constraints which hamper the work of the engineer. I can cite my own state in which we have had for many years a gasoline tax which is sacred to the building of highways. None of that money can go into transportation systems that might avoid the building of some of the highway systems. No, the money dribbles through the gas pumps into the State Highway Department, which can go its merry way building freeways, bulldozing their way through communities that don't want freeways and there is nothing that can be done about it. Even the legislature has no control because it doesn't control the money. That is what I mean by political contraints. The engineers in the state highway system may be unhappy with what they are doing and may not like to fill the cities with these concrete worms but they have no alternative. Then we come to the question of aesthetic considerations with which engineers are sometimes faced, or perhaps they don't even have an opportunity to consider them. As an example, I might cite something I saw in an editorial in a recent issue of Life magazine entitled, "The Second Battle of Antietam," and it starts out, "In the holy writ of the engineers who design transmission lines, the first commandment is 'thou shalt not deviate from a straight line between point A and point B.'" Well now, this isn't wholly the engineers' fault. The big fight that led to the editorial is over a transmission line proposed through some of this very historic country. This is a unique situation. What added cost can the system bear to preserve beauty and history? I've seen other situations in which aesthetic considerations have not been given proper attention. For many years our electric power utilities have been negligent in not pressing for cheaper and better methods of putting thier distribution underground, to improve the appearance of our cities, and also to derive some benefit in the form of less trouble from outages. The engineer also has to be concerned with cost benefit analyses, and some of these can be stated in terms of numbers and in terms of dollars. But there are things called nonvendable benefits, things on which one can't put a price, such as aesthetics. Recreational advantages and things of that sort can't be priced. Nevertheless, they are very important to the future, and engineers should be aware of this. The engineer should make alternative choices known to the public so that informed decisions can be made.

Engineers have a responsibility to the profession for standards and professional development. Also, the engineer is a citizen who has special skills and knowledge, and as a citizen, he has a responsibility to speak up and offer technical guidance, information, and opinion based on that knowledge. An example is the question of more dams on the Colorado River. As a practical fact, the more dams built on the Colorado River, the less water would flow down the river because that is an area of extremely high evaporation. So, increasing the exposed surface area results in less water in the long run. There is a loss of beauty and great geological resource that would be inaccessible from flooding more of the Grand Canyon area. There are better ways to get power to pump water up from the river to take care of some of Arizona's agricultural needs. These are subjects on which some of our public spirited engineers have spoken out. These men have taken some criticism, yes, but they have also received praise for letting people know that there is a way of meeting the power needs other than the way the Bureau of Reclamation said it had to be done.

For the future, by all available indexes, engineering and science will represent an increasingly large component in the gross national product and in total labor force. This will call for a large spectrum of skills for supporting technological people, the professional engineers, and the manager types, whether they be engineers or not. To meet this spectrum of skills there should be a variety in education. Everything points to more education of all types. Particularly, for some people at least, we should offer a much broader form of education than anything we have envisioned so far in our engineering curricula. The humanistic and social science fraction of the curriculum should be expanded and better integrated with the mathematical and physical science fraction. Some people have suggested that possibly a basic baccalaureate in engineering science or fundamentals of engineering be followed by graduate work in the social science areas, such as sociology, economics, political science, and so forth. I don't know. Nobody has developed this curriculum as yet and I don't know if it is right in kind. There is, however, and without doubt a need for some of Douglas Brown's engineers to live and work by David Hume's concept—that we are united in society and dependent on each other. Thank you.

editor's prologue

In the year 1824, Sadi Carnot the French military engineer, already referred to by Dr. Lindvall, published a book in which he outlined an ideal cycle for a power producing engine. In practice this cycle has never been attained by anyone. Yet, it is to this very day used by engineers as the ultimate ideal to which they can strive in designing engines for the production of power. Since Carnot sereval men have modified this work in order to arrive at cycles which though still in the ideal category were in fact closer to what could be attained when technological considerations were taken account of. Thus, Dr. Rudolf Diesel in 1892 proposed the now well known Diesel cycle, which is the technologically workable ideal for the compression-ignition (Diesel) internal-combustion engine. The theoretical work of Beau de Rochas (1862) followed by its implementation by Nicholas A. Otto (1876) produced what is now commonly known as the Otto cycle or the technologically workable ideal for the spark-ignition (Otto) internal-combussion engine used in most of our automobiles. Similarly the work of William J. M. Rankine (1820-1872) resulted in a modification of the Carnot cycle known as the Rankine cycle, a technologically attainable ideal now used throughout most of our electic power producing plants using either fossil-fuel (coal, oil or gas) or nuclear energy. It should be emphasized that the last three cycles have no more been attained in practice than the Carnot cycle, yet all of them serve as a guide and guide-post for designers. Thus professional designers of power plants have historically started with a hierarchy of ideal systems and attempted to have their designs achieve these ideals. An approach at the other extreme might have been to start with rubbing stones together and by trial and error or intuition improve the operation until such time that some net useful power was produced.

Professor Nadler in his paper, in effect calls on those engineers who operate in the socio-economic arena designing or improving business operations; hospital operations, educational operations, etc., to adopt the philosophy proven so successful in the design of engines rather than follow the study-what-exists-and-improve approach. His call is not an idle call by an armchair spectator. He has in fact demonstrated the value of his approach in several industrial as well as hospital settings.

ENGINEERING RESEARCH AND DESIGN IN SOCIO-ECONOMIC SYSTEMS

Dr. Gerald Nadler

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Although engineering is becoming more involved with a broad range of society's problems, and as conventional and new technical problems become more complex, it is developing a philsophy, a sense of its history, an international awareness, and a conscious study of previously off-limits concepts. As examples of these trends consider that design needs along with scientific competence are emerging in an engineering philosophy, historians of engineering are finding their place in more universities, the engineering college at Madison is starting a program to bring engineering concepts to the foreign area studies programs and vice versa, and one engineering curriculum at Madison is permitting foreign languages to substitute for English in addition to the typical 15% of all courses required in the humanities.

I want to talk tonight about these coming influences on classical engineering areas as well as the role of engineering in society as a whole. However, there is so much happening that I will explore just a couple of points with sufficient illustrations to give you a feeling of the depth of the engineering commitment to these emerging interests.

Specifically, I want to challenge a basic philosophy and attitude in the teaching and practice of engineering. Physical sciences and mathematics are firmly established with the role in engineering as they become more necessary and prevalent than ever before. Dean Rosenthal points this out by noting that the name of the College at the University in Milwaukee is the College of Applied Science and Engineering.

Strategy in Engineering is Critical

My point is that there is a lack of a "science" of design. There is not yet a systematization of design or an understanding of what design is all about, as there is a science, systematization, and understanding of research. Design is a central role of engineering and yet there is no strategy of design.

Science involves a rationale, logic, attitude and philosophy as well as a strategy or plan of attack to achieve its results. Research—usually critical and exhaustive investigation or experimentation having for its aim the revision of accepted conclusions in the light of newly discovered facts—is the methodology or strategy used in science to establish general laws and theories. Design—the act or art of making plans, schemes, patterns, models—is the way useful results are obtained in engineering using the knowledge, laws, and theories developed from research. Yet when a design strategy is stated explicity, it is almost identical to the research strategy. How could two such diverse purposes have the same strategies? And why isn't research into research and design strategies going on? Fortunately, it is under way for both research and design strategies and this paper presents how engineering is questioning its strategy. This omits discussion about the philosophy, logic or attitudes as direct topics, but, with focus primarily on the strategies involved in engineering, these items will be touched as necessary.

Strategy is the approach, plan of attack, or methodology used in seeking an objective. Seeking optimum systems design as solutions to problems is our particular role in engineering. Engineers seek these solutions by utilizing the resources of mankind and of nature for the benefit of mankind through the application of mathematics, natural sciences, and experience. This engineering objective is also one now being subjected to much study and review, but is not the major topic tonight. We will assume that this is the objective we seek.

Strategy, therefore, must involve concepts of creativity, systems definition, optimization, and a program for implementation. The tie together of all facets is achieved in a step-by-step strategy, attack or approach that an engineer uses in seeking a particular problem solution.

Perhaps some illustrations of what I mean by a particular problem are in order. You should imagine how you would seek a solution to the particular problem. As you do this, you will be using a strategy, in almost all cases based on the research strategy. This will at least demonstrate that everyone follows some strategy or plan of attack, and it is this strategy and its implications for society about which I want to talk tonight.

(1) Traffic flow in a city. This problem obviously involves many components with many complex interrelationships. Yet there is a particular objective which needs to be achieved. How would you go about trying to solve a traffic flow problem in the city? What would you do first? What steps would you follow? Almost all people would immediately respond with an analytical approach which is the research approach. Analysis will be used, as later discussions will show, but at a much more appropriate time.

(2) Loading dock in a warehouse. A real project, on a completely different level, this started with an engineer in the warehouse of a multi-plant, multi warehouse company in Canada. He suggested a $25,000 expenditure for a piece of equipment which would almost automate a section of the loading dock. The rate of return was quite good, payback in much less than 1 year. It was approved by 4 levels of management before the vice president asked two staff men to review the request. What strategy or plan of attack should be used to investigate the necessity for and rationale of this particular expenditure?

(3) Development of an Industrial Engineering curriculum for an engineering college. Notice that the desired results, like all the other illustrations, is a specific solution or "system" to achieve a specific purpose in a specific setting or institution. What strategy, plan of attack, or step-by-step methodology would you follow in designing such a system?

(4) Gasoline tank cover on an army tank. This covered has to be designed to admit air when the tank is above water, but exclude water from entering the gasoline tank when the tank is underwater. What strategy would you follow in designing the specifications for the cover?

(5) Regional medical program for heart, stroke and cancer. Dr. Hirschboeck's presence in the audience reminds me of this system problem. He is the Regional Coordinator for the Wisconsin Regional Medical program. The problem is to

design health systems for delivering the best heart, stroke and cancer care to the citizens of the Wisconsin region. What strategy would you follow for this system problem?

(6) Credit system in a large oil company. Credit purchases of oil products and subsequent invoices and payments constitute a large system problem. One company set up a project team that spent 2500 man hours using a conventional strategy to study its credit system, and no changes were made. Another project team was formed a couple of months later, and it used a different strategy, the one discussed later, to achieve very significant savings. What strategy would you recommend for the new team?

I could give you many additional illustrations, but this broad spectrum, including several socio-economic systems, will suffice in showing the fact that a strategy is involved in seeking solutions. As a general statement, problems of any size in any type of organization with any range of technologies are solved with a strategy. In the broad sense, each of these projects is an engineering problem, and the broad engineering question I am addressing is what strategy *should be used* in designing an optimal system to achieve a particular result. I will refer later to several illustrations and show how the appropriate strategy produced excellent results, better than any conventional strategy.

Importance of Investigating Strategies

The illustrations of problems I have presented are critical in our society, and the way solutions are sought is likewise critical. There are several reasons why the critical strategy situation exists for engineers.

(1) It is extremely important, in the context of our world today, to achieve the "best" designs and solutions when tackling any of these projects. We cannot afford many errors in proposing a solution. Time is often critical and an error pushes the problem into even greater complexities because of the lost time.

(2) Society needs to maximize the utilization of the scarcest national resource of all, human beings, as well as of material and financial resources. We, as engineers, have done very little to maximize the utilization of human resources comparable to what we did for natural resources, such as coal, oil and iron.

(3) Better education of engineers, and others, can be achieved by emphasis on the proper design strategy. Why should we teach them an approach to or strategy for design which is not correct and hope that the student will intuitively find a better approach? After all, a good strategy does exist, as illustrated by the approach used by the creative genius. Research shows that these creative people do use a different strategy. Why not teach our students the correct strategy?

(4) Although this is an internal-type problem, it is important that engineering departments in industry, and even in universities, be organized to optimize utilization of the engineering resources rather than to apply techniques. We find in industry, for example, that we no longer have just a mechanical engineering problem; we have metal cutting problems that do not rely solely on what has been classically called mechanical engineering. We no longer have electrical engineering problems in industry today; we have circuit control problems which rely on many other fields in addition to electrical engineering. An appropriate

strategy for designing organizations would emphasize functions or purposes instead of techniques or possible specific equipment for achieving function.

Today's technology shows great interdependence of knowledge and disciplines. An engineer needs to obtain the best of two worlds: the knowledge developed by the sciences on which engineering relies and the problem orientation—or design—that started and has classically been the role of engineering.

With this background, the particular points I want to cover will (1) show how a universal definition of system permits all of the illustrative projects I presented earlier to be viewed in the same system context, and (2) describe a design strategy that permits any system, regardless of size, scope, or technology to be approached with the same plan of attack to assure the best possible design for immediate use.

Univerisal Definition of System

I suppose if I asked everyone in this room to define a system, we would probably get as many different answers as there are people. For example, people often define systems in terms of size: a system will be anything that involves 25 or more people. Or in terms of cost: a system must cost $100,000 or more. Or in terms of complexity: a system has to have many interrelating factors. Or by putting an adjective in front of the word system: *production* system, *accounting* system, or *purchasing* system. The latter statements do not really define the word system; they place the word system after the adjective. As much understanding is obtained by just saying production, accounting and purchasing.

Defining systems either by cost, size, technology, or complexity is normative and does not provide a definition that aids the need to design a system. A system definition ought to be prescriptive or defined in terms of the basic elements that comprise it to enable an engineer to "use" it.

I would like to define a system in terms of seven basic elements which are present and applicable in design settings regardless of the kind of project or of the technology involved. Figure 1 illustrates the seven elements.

Think seriously about any of the projects mentioned, whether about the gas tank cover or the curriculum in industrial engineering or the warehouse problem, for example. Each is described by the following definition of a system, and you should mentally relate the specifics of the system you have selected to these elements.

Figure 1 represents a system as a hopper. A larger hopper means a bigger system and a little hopper a smaller system. It is even possible to put a hopper around any one of the circles and the same seven system elements describe that small system.

The first element is *function*. Every system must have a function. And if there is one mistake made in system design efforts today, it is to forget the fact that a system must have a function. The function is the mission, aim or purpose of a system. *What* is the system supposed to be accomplishing, not *how* it is to be accomplished.

The second system element is *inputs*. Inputs can be of three different types: physical input, such as a coil of steel to processed in manufacturing or food to be processed into dishes to be served to people in a cafeteria line; information input of any type, such as verbal, written, holes in a card, or magnetic orientation on a

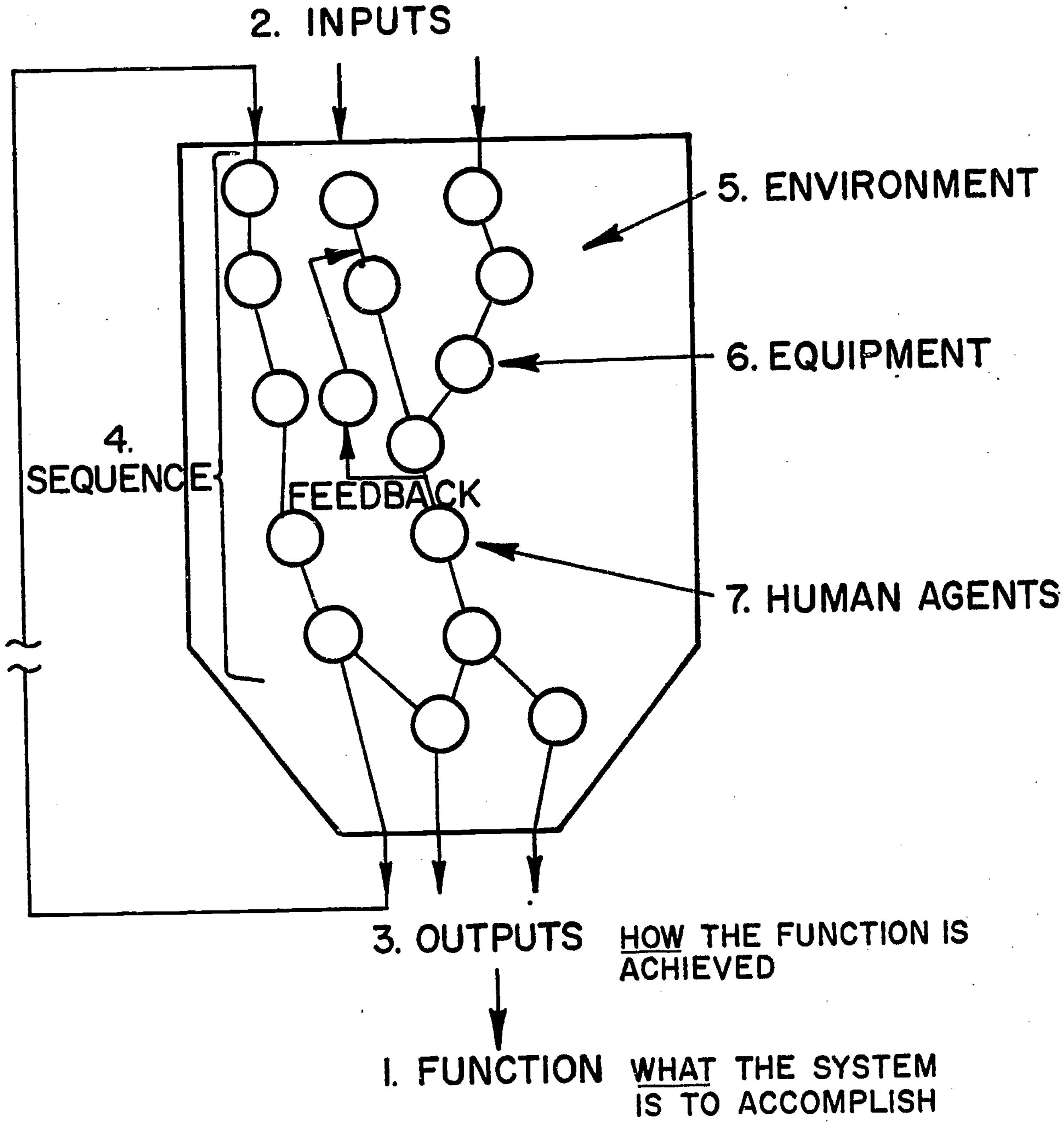

FIGURE 1 A System as a hopper.

tape; and human input that enters the system to be processed. Feedback input of any of these three types refers to output which enters the outside world and may return to the system again as inputs.

The third system element is *outputs*. Outputs are the end result of converting the inputs. They are one or a combination of the three types of input. Notice the important difference between outputs and function. These are not the same; one of the biggest mistakes in systems design is to assume that the output is the same as the function. For example, take a common mechanical pencil. What is the function of the system or manufacturing these pencils? Most people say the function is to make pencils at a profit. In reality, the function of the system is to produce an instrument to record information. The output of *this* particular system is this particular mechanical pencil. There is a great difference; just ask the manufacturers of pencils at about the time ball point pens were introduced. Ball point pens have the same function, but the output is different.

The fourth system element is *sequence*. Sequence is the order of or steps for converting the inputs into the outputs. Even though feedback or control systems have the same identical system elements being described here, they are often part of the sequence when the sequence or hopper, as shown in Figure 1, is large enough. The sequence alone is frequently considered to be a system in today's world. Yet in this definition of a system, it is only one of seven elements.

The fifth element is *environment*. Environment can be of two types. It can involve physical environment, such as heat, light, noise, dust, color on the walls, etc. It can also involve attitudinal environment, the managerial atmosphere generated in the organization. It is a permissive organization, an autocratic organization, or a democratic organization? Important in the systems idea is the concept that the environment in many ways can be designed along with the more specific elements of all the systems that share the environment.

The sixth system element is *equipment*, or physical catalysts. Equipment is any physical item which helps convert the inputs into the outputs, but does not become part of the output. Notice that this definition differs from the economists' definition. The economists define any resource that enters an organization as input. This definition separates them into those items, the inputs, which are to become part of the output, and those which are equipment or physical catalysts in making the conversion.

The seventh system characteristic is *human agents*. The people and the methods they use aid in converting the inputs into the outputs, but do not become part of that output. Therefore, human agents and inputs differ. For example, through one door of a hospital may come a person who enters that hospital as a patient. By this definition that person is an input. Through the same door may come a nurse; by this definition the nurse is a human agent who aids in making the conversion of inputs to outputs.

This definition of a system applies to any one of the illustrative projects I mentioned and all of the others you can think of. It is universally applicable. It represents the elements and dimension an engineer should consider as he designs a system. To be more specific, when an engineer is designing a system of any sort he ought to be reviewing the design matrix (see Figure 2). The design matrix defines the cells of information which should be reviewed and filled in to prepare a complete design for that system.

The design matrix uses the seven system elements as the rows and the dimensions as the columns. The dimensions are physical, rate and state. When each element row is completed, the system we have in mind is fully designed. The physical dimension is the one most commonly thought of when discussing a system design. The physical dimension is the tangible, overt, observable, or real life element of a system. The physical dimension of output for the mechanical pencil specifies ¼" diameter, 5½" long, white top, black plastic base, etc. These specifications represent the overt, tanglible dimensions of the output of this system. The physical dimension must exist or there can be no other dimensions.

The rate dimension represents some measure or measures of the physical dimension per some unit of time. For example one output rate dimension might

	PHYSICAL	RATE	STATE
FUNCTION			
INPUTS			
OUTPUTS			
SEQUENCE			
ENVIRONMENT			
EQUIPMENT			
HUMAN AGENTS			

FIGURE 2 The Design Matrix defines the cells of information which should be reviewed and filled in to prepare a complete design.

be 1000 pencils an hour. A sequence rate dimension might be processing 3000 pencil barrels per hour. The environment rate dimension might involve the number of times per hour the air is completely circulated.

The state dimension refers to the anticipated stage of physical and/or rate dimension at some point in the future. The state dimension represents the dynamics of an engineering system. We cannot say that the physical and rate dimensions for the traffic flow problem will remain the same as today. An engineer must design the state dimension by defining each system element in terms of its expected stage at sometime in the future. This applies to the design of each system, such as the gas tank cover and the engineering curriculum; each must be for today as well as whatever changes can be planned and anticipated. The state dimension provides for continuing orderly change in a system. We should not design a system in today's world unless we design into it the dimensions for change.

A system is considered designed when all necessary information, usually in the form of models, is placed in each cell of the design matrix. The information describes how the whole system is to operate. The design matrix is a convenient summary of the definition of a system. An engineer can review any kind of project, such as those presented earlier, with the same fundamental definition.

This does not mean that the definition will never change, for research is underway to determine, for example, whether or not the design matrix ought to have a control dimension. As of now control specifications are included as a physical dimension. This appears best now because control is literally part of most of the system elements if the system is large enough. In addition a control system can be treated as another system with seven elements. Thus control is not omitted in any way. However, research continues to investigate the feasibility of changing the three dimensional specifications of seven system elements.

Some observations about the design matrix illustrate its utility. Each cell is not filled in. The engineer or designer must review each cell to determine if information is necessary. This assures the designer that all possible factors involved in the system are considered.

If a designer gives me the 21 cells of information for a particular system, I should be able to go any place in the world and, given the resources there, establish that system exactly as it might be set up here. I will not dwell on the mechanisms or techniques used in detailing this information, but models or abstractions of the real life are inserted in the cells as they pertain to that particular cell. Models are the main topics taught to engineers, often including over 90% of engineering subjects.

The Concept of Strategies

Knowledge about the definition of a system and about all of the models that could be used is not sufficient in defining the strategy a designer or engineer should use in finding the information to be placed in the 21 cells. The strategy is rather critical in helping the engineer to develop the best possible system for the problem at hand.

All of us use a strategy in seeking a solution to a problem. It can be called a problem solving approach, an engineering method, operations research, or have no name at all. Let me try to characterize the strategy all of you probably followed, regardless of what you call it, on the illustrations I mentioned before.

Figure 3 illustrates the conventional design strategy I think you used. The first step is to identify a problem or existing system illustrated by the first rectangle. Of course, I gave you the problem or system.

The second step divides the system or project into subdivisions or components, or analyzing the existing system and breaking it into smaller units. This is fitting a model to the system.

The third step is to manipulate the model, reviewing the various components, to find what is wrong with them.

The fourth step then makes the changes and installs the recommendations.

As an illustration of how pervasive this strategy is, consider the problem of designing an industrial engineering educational system (curriculum). When ing Curriculum at the University of Puerto Rico, the chairman of the Department told me they had an analysis of all their existing courses by detailing the outlines, listing all the problems and exercises, and identifying all the text books. He suggested we start by reviewing all this analysis, course by course, and I could then criticize what had been done. In effect, the chairman of

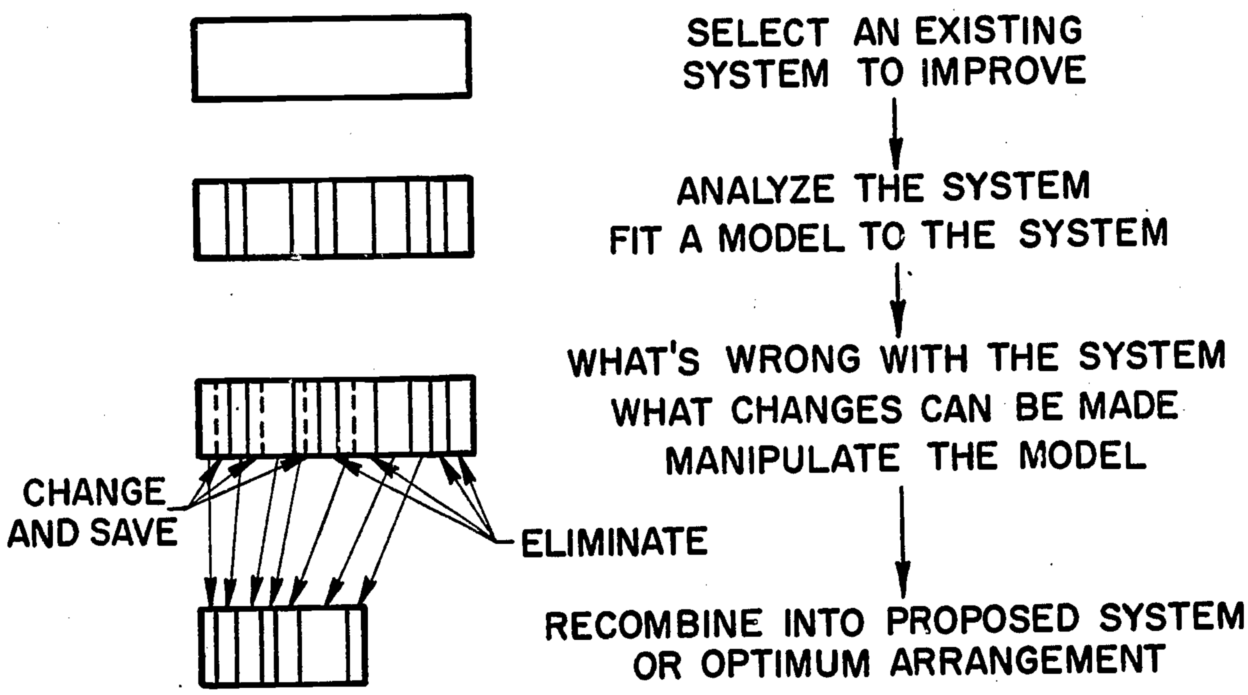

FIGURE 3 Schematic of the conventional system.

the department had identified the curriculum as the existing system (step 1), broken it into components (step 2) and then asked me to help them review the analysis and subdivision to find how the system might be modified or changed (step 3). It is obvious that what I suggested we do follows the design strategy I will describe in a moment, but you should recognize that the conventional strategy is followed almost all of the time.

It is interesting to note that an engineer follows the same strategy even though he might be designing a new system. For example what would be your probable first reaction if I were to ask any of you here who had never designed a plant for manufacturing mechanical pencils to now assume the responsibility for such a system design project? Following the conventional strategy, it would be "Let's find out what is done in other pencil manufacturing systems." You would go to some other facilities to learn what is happening now. Notice this is analyzing the system, then checking it to see what might be changed to arrive at a system you could call your own.

It is this point which is questioned by most of the research now going on. A review of the structure of the conventional strategy shows that it is based almost identically on the research strategy, a strategy used to identify general laws, theories or principles. It should be apparent that research for developing laws, theories, and principles is much different than design for detailing a specific system solution for a specific set of circumstances. Research, in seeking a generalization, law, or theory, is inductive or seeks a generalization to unify a series of facts. Design, on the other hand, is deductive. It seeks a specific answer deduced from the generalizations, theories, laws or principles. These purposes are almost diametrically opposed, yet the conventional strategy is an almost one-for-one mapping of the research strategy.

I am not claiming that the research strategy is bad; the research strategy should be used when seeking a generalization, law, theory, or principle. I use the research strategy often, both at the University and in industry. When you need to develop a generalization, then you use the research strategy. When you need to design, then you should use the design strategy I will present.

The two strategies do intermix. For example, we were designing a data processing system for physicians' orders in a hospital. This project sought specific solution for a specific set of circumstances. As we were proceeding with the design strategy, we found that a particular generalization was not available; what are the characteristics or distributions of physicians' orders? At that point, we stopped and did research with the research strategy. We gathered and analyzed existing information to give us one of the generalizations we sought, for example, a negative exponential distribution relating the frequency of orders with the types of orders. The research strategy was used to find this generalization within the design strategy for the whole project.

To complete the concept of strategies, let me mention a third strategy, an operating and controlling strategy. The manager or the person who operates a system should use a strategy that is different from either the research strategy or the design strategy. Time does not permit us to pursue this strategy except to mention that it exists.

I think it is unfortunate that the conventional strategy is used for design. It gives a solution which is very limited. It puts blinders on the eyes of the designer, and does not utilize properly human resources because they become involved in what is wrong instead of in what should be done. It forces engineers to adopt a technique orientation, that is, finding where a technique can be applied rather than what problem needs solving. It also causes people in organizations to defend the necessity of and present methods for a system just because so much detail about the systems in which they work is presented in an unfavorable light.

A Recommended Design Strategy

The design strategy I would like to present is called the IDEALS Concept. The word IDEALS is an acronym for Ideal Design of Effective And Logical Systems. I will present solutions to some of the problems I mentioned earlier, point out how the results using the IDEALS Concept strategy are better than those from the conventional strategy, and discuss how this kind of empirical work is developing a strategy which is more useful to and providing better solutions for engineers, for new socio-economic problems as well as for more usual problems.

The IDEALS Concept is the systematic investigation of contemplated and present work systems to formulate, through the ideal systems concept, the easiest and most effective systems for achieving necessary functions. Let me explain this definition.

Systematic investigation merely says that this strategy will present a step-by-step approach or plan of attack. It will be orderly but it will not necessarily be based on the research strategy.

The phrase *contemplated and present systems* means that the strategy is not restricted to just those systems which are in existence.

The same strategy can be adopted regardless of the condition of the system's existence — one that doesn't exist, one that does exist in difficulty or in trouble, or one that exists in a satisfactorily operating state.

The word *effective* introduces the idea that efficiency is not the sole criterion for systems design. Rather a measurement of how well the function is achieved (effectiveness) is more important than how efficient the system may be. Efficiency is included in effectiveness but effectiveness means more than just efficiency. You might, for example, stay in your office and design an outstanding, efficient system for manufacturing, say, lecterns, but when that system gets into operation it may not be very effective. Perhaps the people and the skills or talents they represent may not particularly like your system, and thereby greatly reduce its effectiveness.

For achieving necessary functions is one of the most important parts of this Concept. There is nothing more disconcerting than to find a very elegant and efficient system that is not necessary, where the function is not really required. For example, a sophisticated electronic inspection device in a radio tube manufacturing plant took two years to build. After it was installed someone noticed about six months later that there were no rejects. Why? The very dimensions the machine was inspecting had been designed out of the product about 18 months before the machine was installed. As another example, consider the system I saw for removing paper and glue from the front of chrome plated stainless steel sheets. It was a beautiful layout, very efficient in its flow and the way people operated the system. I asked, what is the function of the system? After consideration, my host said that they, the fabricator, assumed that the vendor put on the paper and glue to protect the front of the sheet in shipment so it would not get scratched. The vendor assumed that the fabricator wanted the paper and glue to protect the front of the sheet as it was being punched and stamped through the fabrication process. And neither one of them wanted it. For a third example, consider the warehouse I mentioned earlier. The engineer in the warehouse recommended a new piece of automation equipment for the loading dock. The equipment cost $25,000 with pay back period of much less than one year, thus providing a very good rate of return. It was then approved by the supervisor of the warehouse, the manager of the warehouses, and the director of distribution. When the request reached the vice-president, it was given for evaluation to a group that was using the IDEALS Concept strategy. Their solution was to *sell the warehouse*. The $25,000 worth of equipment would have technically returned the cost in less than one year, but the correct solution was based on ascertaining the necessity of the function.

The middle phrase, *through the ideal system concept,* is the last we need to consider. The basic idea is rather simple and I think each of you can understand it. In the conventional strategy you are asked to analyze the existing system. You therefore use the information of this analysis of the existing system, usually a lousy, problem-ridden system, as your guide in developing a recommended solution. In the ideal system strategy, we design the best system possible, literally design it, and then use that information as our guide in developing the recommended solution. It is a very simple idea. It is obviously a lot more difficult to implement and that is the role of engineers and systems designers. But the critical difference of using the information developed from designing the ideal system to serve as the guide provides much better recommended solutions.

An additional look into the ideal system concept is helpful. The work system to be used should be as close as possible, compatible with the restrictions of the situation, to the ideal system for ideal conditions. The system to be installed *now* is critical in this definition. The system must be implemented *now,* not later. But it should be developed by designing the ideal system for ideal conditions before making it compatible with the restrictions of the situation.

A key phrase here is *ideal conditions.* We call this regularity. Identifying the regularity units of the system as the basis of developing ideal systems is a critical part of the strategy. Imagine for example, how you would design a system to manufacture pencils. The conditions would be far more ideal for the design if there were unlimited distribution, unlimited resources, and only one model of pencil to design the system for. These represent a set of conditions we call ideal. Now then we design the system for that set of conditions, and then, and only then, make it compatible with the fact that we have 14 different colors and 53 different styles of pencils. Literally, this is what happens in the IDEALS Concept. The strategy develops the best or ideal system for the ideal conditions and then makes it compatible with real life.

The triangle in Figure 4 illustrates what is meant by ideal systems. Let the distance between the legs of the triangle be equivalent to cost per unit. Every system has a unit output whether it's a service, product, or type of information.

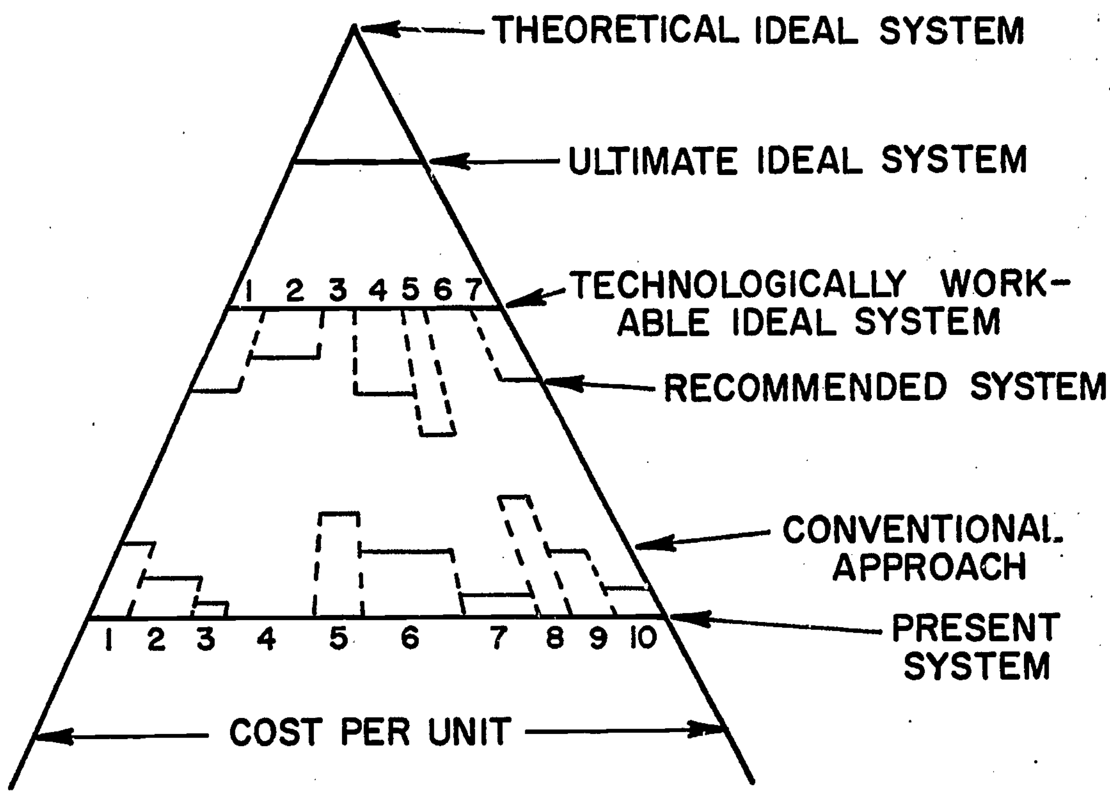

FIGURE 4 Levels of ideal systems.

A cost for that unit output can also be identified, whether it is a gas tank cover, traffic flow system, or whatever. Other criteria, such as time or energy can also be used, but cost is the most general and the one most of us understand.

The apex of the triangle represents no cost per unit and this level is identified as the theoretical ideal system. But one never designs theoretical ideal systems just as one does not count to infinity. You never get to infinity and you never reach a theoretical ideal system. But the theoretical ideal system fulfills the same role in the IDEALS Concept that infinity fulfills in mathematics. It is a limit value. If someone asks me how far can I go in designing a system, the answer is to the no cost per unit limit. No cost per pencil for example. No cost per lectern. This limit value defines a direction which is quite important, just as mathematics could never have developed as it has today without a concept of infinity. It would be very difficult if at all possible to have a good design strategy without a theoretical ideal system or limit value toward which everyone moves in design activities.

The next level is ultimate ideal system, which is a level actually designed. The ultimate ideal system is one that cannot be used today because further research and development is necessary before it can be made practical. For example, in manufacturing washing machines and dryers, one of the ultimate ideal systems was to have clothes that don't get dirty. If any one develops this at all the company might as well do it because it will gradually put them out of the business of making washing machines and dryers, but into the business of making clothes that do not get dirty. This company is doing research on this topic. Another ultimate ideal system is the one developed for the system of processing physicians' orders. One component of this system involves a device which would take the spoken word of the physician and translate it to some written, magnetic, or punched form for further processing. These are ultimate ideal systems, because they cannot be installed today without further research and development.

A technologically workable ideal system (TWIS) is exactly what it says, a system that is technologically workable for the ideal conditions. Everyone, I am sure, agrees that it is possible to design a completely automatic system for manufacturing a particular mechanical pencil which represents one condition called ideal. But a TWIS may not be installed because other conditions and restrictions of the real life situation must now be incorporated. Customers want colors in pencils other than black and white. They like 14 different colors, and a variety of other styles. Therefore each component of the TWIS is reviewed to develop alternatives to the ideal system components that are as close as possible to the ideal system guide as possible. Thus the recommended solution comes as close as possible to the TWIS. Notice, for example, components 4 and 7 are installed exactly as designed by the ideal system.

Figure 4 illustrates the three important advantages that are accruing to engineers who are using the strategy. The first advantage is that a better system is designed. This has been shown by many case illustrations where the opportunity presented itself to compare the results of two groups of engineers and professionals designing the same system, one group using the conventional strategy and the other group using the IDEALS Concept. For example recall the warehouse system presented earlier. The engineer at the warehouse used the conventional strategy. He recommended one solution whereas the solution recommended by the people using the IDEALS Concept strategy was much better. The credit system in the large oil company, another example, was studied by a project team using the conventional strategy. They spent 2,500 man hours and recommended a solution that was not installed. Therefore no result. A little later another team using the IDEALS Concept strategy spent 900 man hours and recommended a solution, which is installed and operating today, saving $1,200,000.

The second advantage is that it takes less time to design the better system. This might surprise most of you because you thought that designing an ideal system requires a great deal of time. It does not. The time in conventional strategies is spent analyzing the existing system which the IDEALS Concept greatly eliminates. In addition, a start which analyzes everything about the existing system never gives a clue about what information is needed. You have probably have had the experience of asking your boss, or someone ask you, what information should I gather for this particular project. A shrug of the shoulders is the usual answer, along with "I don't know, you might as well get it all." A great deal of information gathering takes place with the conventional strategy, and most information is never used because the conventional strategy provides no guides to determine what information is necessary. By developing the ideal system first, a clear specification of the information needed is available, and then only that information is gathered, thus saving time. Our resources, in the form of the time of our engineers and professionals, are utilized much better by having them look at what is necessary and essential rather than just gather any helter skelter information.

The third advantage is just as important as the first two but is especially important for those of you that may not believe the first two. When the recommended system is installed, built-in change is also installed because the changes that can be expected are already designed. The installation of a system derived with a conventional strategy very seldom includes any idea of what changes might be made in that system. As a matter of fact, the conventional strategy makes the designers so glad to be able to install some changes that they forget the fact the system can be made even better at some future point in time. This need is essential regardless of the type of project, and is just as important as any other benefit of the IDEALS Concept.

The design strategy in the IDEALS Concept involves ten steps. The first is *function determination*. This step means more than just the function of the system that starts the project; it means identifying the function of the system that should be designed. Function expansion is used in developing the necessary hierarchy of functions. In most cases, the selected function is different than that for the originating system. This step thus ascertains the necessity of the system. Is the system really necessary, or, conversely, is the system being designed for a necessary function?

The second step is *ideal systems development*. Develop several ideal systems from which the best guide called the technologically workable ideal system target (TWIST), can be selected for the system. The establishment of the ideal system guide raises many questions which leads to the next step.

The third is *information* gathering, concerning the much more pertinent questions. In addition, this means that much less information is gathered than is the case in the conventional strategy. Research may also be performed in this step, as was the case in determining the characteristics and nature of physicians' orders in a hospital. It should be clear that this strategy enables engineers to identify what information is essential and deal only with that research or information. Sometimes this reduces data collection as much as 95%.

The fourth step is *alternative suggestions.* Some of the gathered information may point out that a component or two in the TWIST are not usable. It is thus necessary to develop alternatives to incorporate the exceptions. The pencils, for example, are needed in 14 colors instead of 1.

The fifth step is *select the feasible system.* Which of the many alternatives should be combined into the whole real-life system for the particular situation is a question that involves trade-offs among the various criteria for evaluating the systems.

The next five steps are: formulate and optimize the details of the system, review the system details, test the system or some components, install the system and establish performance measures. The last step enables an orderly transfer of the system design to an operator, controller, or manager who will operate the system.

Throughout steps 3 through 10, the TWIST or ideal system guide is used as a continual reference to keep the actual system as close as possible to the ideal system. In addition, all steps are iterative, rather—than followed in monolithic fashion one step at a time.

Illustrations of Applying the IDEALS Concept Strategy

Several engineering type illustrations have been presented already, along with one for designing a curriculum. One other socio-economic system should help illustrate the strategy in another context. A project of the past few months is systems planning in a broad context that I think illustrate how the general concepts can be applied. Consider the Wisconsin Regional Medical Program for heart, cancer, and stroke. With the first step concerned with function, it is apparent that health care is a very difficult system to design. To assist in this step for such a system, a technique called system pyramid is used to identify functions of the system (see Figure 5). The prime function is health care for the citizens of the region as shown at the apex of the pyramid. This function is divided into subfunctions, care for heart, stroke and cancer, alcoholism, mental health etc. Then the next area of interest under heart, cancer and stroke care is divided into the functions of prevention, diagnosis, treatment and post treatment health care. These functions can be further subdivided as shown in Figure 5. The results of this will be the identification of all the functions to be considered in providing health care in heart, cancer, and stroke diseases. At this point in time, the planning committee is starting to design ideal systems for functions of greatest need, which can render or provide that service for the citizens of the region. The remaining steps will then follow logically. Quite important is the fact that very little time has been wasted on collecting information which the conventional strategy would have required. This feature, plus the comprehensiveness of the program, has already attracted the favorable attention of those responsible for all the regional medical programs in the country.

Conclusion

The engineer of today is progressing both in technical developments, such as plasma gases, laser beams, powder metallurgy, and computers, to name just a few, and in understanding the engineering design strategy and applying it in diverse fields, such as whole educational systems, broad government agencies, building industry, and those I have mentioned tonight. It seems fortunate to me that engineers are broadening their areas of interest in terms of applications, doing the research to provide themselves with new knowledge in undertaking new types of projects, and educating themselves in a broader range of disciplines in preparation for this work.

The involvement of engineers in today's and tomorrow's socio-economic systems is taking place on a much higher level than the crude attempts at social engineering in the earlier 1900's: the engineer is a member of a team, he utilizes disciplines other than his own, he has much better techniques and tools, and he is greatly interested.

I have tried to present only two major items from the whole list of research and design advances that engineers are making: a definition of system and a design strategy. The major points, therefore, that summarize my message are:

(1) There is a definition of system — three dimensions of seven elements — that is universally applicable to old and new areas of engineering applications and

(2) There is a design strategy markedly different from the conventional or research strategy that gives much better results in systems design efforts and can be remembered simply as T H I N K
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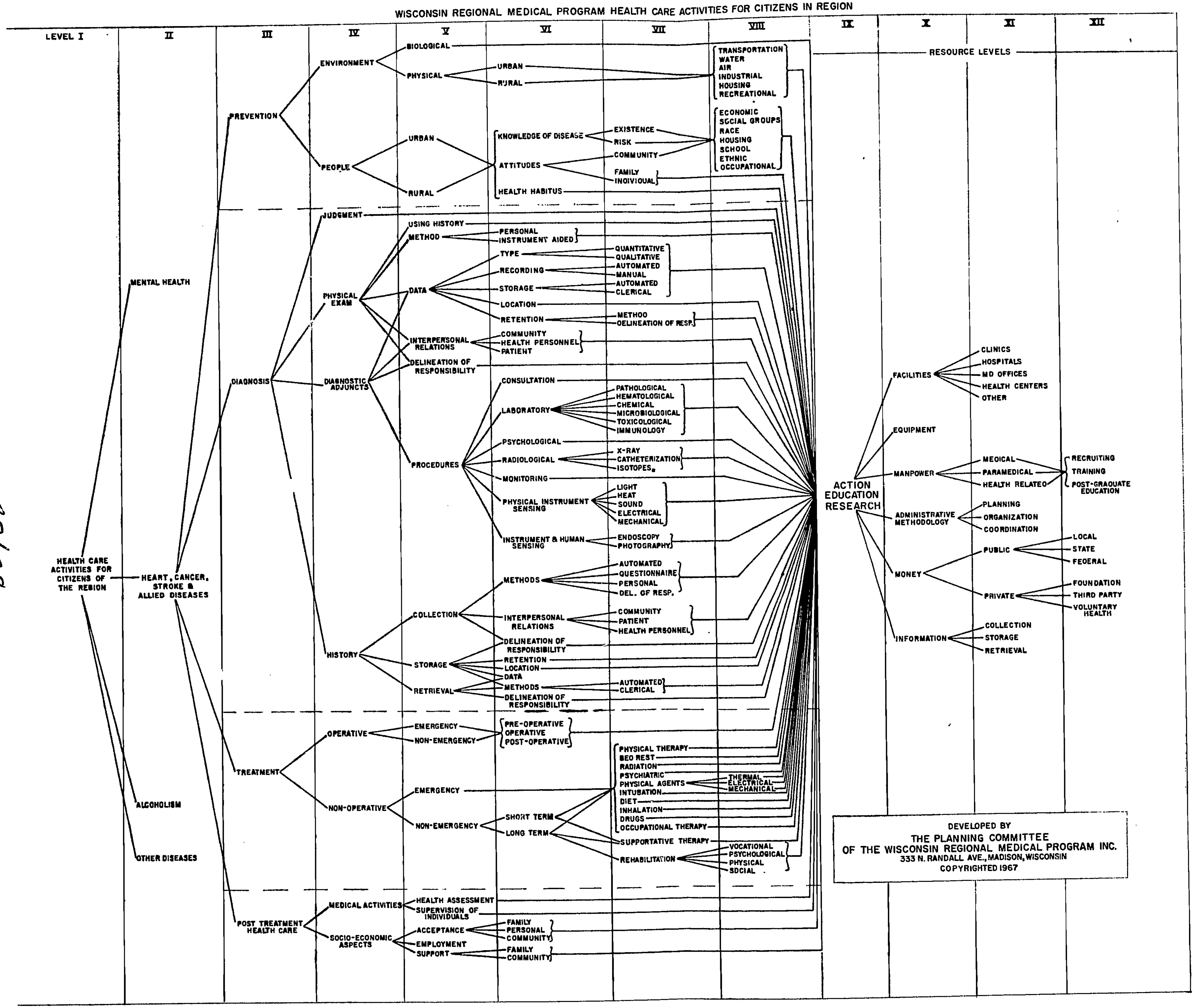

FIGURE 5
Systems pyramid.

editor's prologue

The greatest and most vital resource in any developing or developed economy is generated within a nation's educational sector. This sector produces the trained manpower which is essential to the nation's wealth, welfare, health and security. It produces the elite which sets a nation's higher goals, creates in the arts, reflects in the humanities, generates in the sciences and in technology, but most importantly it regenerates and expands its own ranks. The educational sector is one if not the greatest single user of this highly educated elite. In 1964 in the United States alone over 2,260,000 professionals (1) were employed in connection with the education of its populace from kindergarten through doctoral programs. During that same year over 54,000,000 people were enrolled in various programs. The capital outlay, that is investment in plant and equipment, during the decade ending in 1964 was $57,-900,000,000.

Projections for the future are even more staggering. The 1964 operating budget of 38 billion dollars will be escalated to 61 billion in 1974 according to the U.S. Office of Education (1). Requirements for instructional staff for 1974 are projected to be 3,014,000 i.e., 30% greater than the 1964 figure with the highest percentage increase i.e., 61% in the higher education segment.

This editor estimates that the replacement value of educational plant alone in the United States is well over 500 billion dollars. There is no other segment of our economy which can boast this kind of investment and contribution both in magnitude and in quality to the total effort of raising man's material as well as spiritual standard of living.

Because of the magnitude of this sector of our economy it behooves us, citizens, educators, administrators to time and again ask a simple question "are we spending the money earmarked for education well?" Once in a questioning frame of mind one may ask "are there any methods available for realizing a saving without jeopardizing the quality of education?" Alternately we may ask "with the money entrusted for this purpose can we expand our services either in quality or quantity or both?"

These questions are not at all unlike those asked by and of administrators in industry, commerce, government, the military and also in hospitals. Since the turn of this century, but mostly since the end of the Second World War, and to an ever increasing extent, progressive administrators especially in industry and the military *have turned to quantitative methods in the search of answers to above questions. Administrators of hospitals whose problems are most similar to those administering public and private educational institutions are more and more within recent years turning to this approach. (2) (3) (4) The approach in question can be found in professions of varying names; Systems Analysis, Operations Research, Industrial Engineering, Management Science, etc. Education appears to be one of the most fertile grounds for the application of existing methods of operations analysis and for the development of new techniques. Although several investigators have made strong steps forward in the application of Systems Analysis to educational institutions the "cream" so to speak, "has hardly been skimmed off", much remains to be done.*

In the next paper Dr. Taft outlines some of the applications of Operations Analysis in the broad field of Education.

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DESIGN FOR EDUCATION: A SYSTEMS APPROACH

Dr. Martin I. Taft

This evening I will try to discuss as briefly as I can a little bit about the role of the engineer in looking at socio-economic systems; to mention systems analysis and systems technology; and then to relate some of the work that I have been pursuing in the area of curriculum. It's been my personal observation over the years that the significant problems that we face today are ones that cannot be solved by specialists. The really significant problems are ones that require an inter-disciplinary approach. It is mostly because of this belief that I have tried to integrate some engineering truths with my knowledge about education and my work as a teacher. I believe that an intensive dialogue must be initiated and continued between engineers, educationists, psychologists, sociologists, economists and others, if we are to make important strides toward the solution of problems which are very broad in scope. Such problems involve not only curriculum and teaching matters but also problems which deal with the management of educational institutions.

I would like to tell you briefly the development of engineers over the years through a whole series of steps which are illustrated in Figure 1. As you can see, engineers were not given large sums of money to work on many important

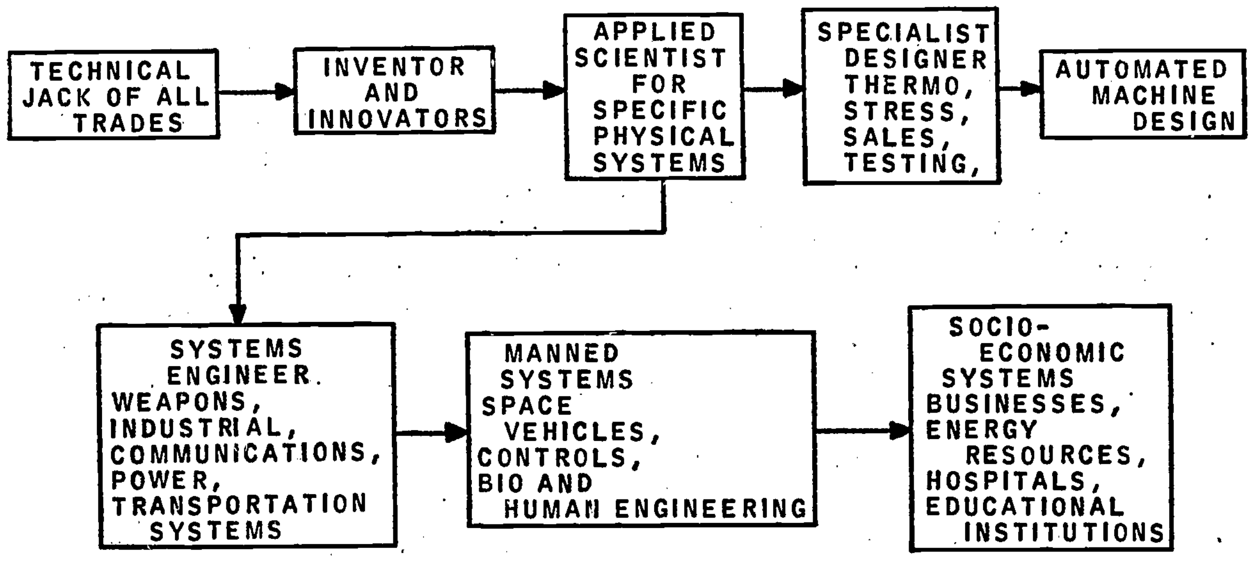

FIGURE 1 Development of engineers.

problems at the beginning. They began by fixing things. As the years progressed and they accumulated experience in this, some of them who spent a little time studying physics, mathematics, and chemistry conceived of things which our developing industrial society required and as inventors and innovators they carried on the process which we now call engineering from its inception through the end. They would conceive an idea, something that our society needed, and then they would carry it through it's analytical aspects, its detailed design through its production and sales, and finally its renovation or retirement. Around toward the turn of the century we reached the point where engineers began to specialize. As the demand for designs with greater efficiency, maintainability, reliability and performance grew, it became obvious that the design process required a broader and deeper knowledge of the laws of nature, e.g. physics, chemistry, mathematics, and so forth. People in the science areas began to turn their attention to practical applications and became known as applied scientists. Simultaneously some engineers entered the field of applied research in such diverse areas as stitistical thermodynamics, hydrodynamics, soil mechanics, electron physics, and solid mechanics. The fine line between the applied scientists and the research engineers grew thinner.

During the 1940's, the engineering profession branched into two major directions. The majority of engineers became specialists: thermodynamicsists, stress analyists, sales engineers, electric circuit designers testing and reliability specialists and many other types. To carry this branch to an absurd or perhaps logical conclusion, the degree of specialization today is so great that we are now offering courses in automated design. Many of the little steps, and many procedures that an engineer uses to design a product or to develop a specific service are being programmed in computers, and the machine will replicate these steps as many times as necessary. The engineer is, in the sense, being displaced by his own ingenuity but he is creating many new jobs. The engineer is now able to turn his attention to many other creative tasks for which he did not have time in the past.

The other path taken by some engineers resulted in the generalists. Rather than specialized, many engineers turned in the direction of designing systems. There was an evolution from small components, to assemblies, complete mechanical and electrical systems, and finally to weapons systems, large industrial complexes, chemical plants, as well as communications, power, and transportation systems. Most of these are systems that are basically mechanical or electrical in nature. The next step specifically after World War II was to enter the area of manned systems. And here we have the individual human being, as well as groups of people as part of the design concept. But the individual has an adaptive decision structure; he has built in feedback loops which enable him to learn from previous experiences. Thus, as man interacts with other components in a large physical system, he is constantly changing his own as well as the entire system's characteristics. This new ingredient made it quite difficult for engineers to run a series of very carefully thought out experiments and to repeat them time and time again with the expectation of obtaining the same results each time. Some of the components were constantly in the process of change. The engineer has, over the years, developed some highly sophisticated tools for dealing with these kinds of systems.

In the last few years, we have turned our attention to social-economic systems. Here the emphasis is more on people rather than on the mechanical devices; on the interrelationships between groups and how they interact with the physical systems as well as with each other. This has traditionally been the province of the sociologists, psychologist, anthropologist, business administrator and social scientists but it is my belief that the engineer can make specific contributions in this area because he has a whole host of tools in which he has proven his success. Many other fields cannot say the same. I believe that one of the major reasons why large sums of money are often not allocated, for instance, to sociologists, by funding agencies is because they have not shown a whole series of small steps leading to success in each case. There is little confidence that the present tools and methods of the sociologists are sufficiently refined to warrant their application to the great socio-economic problems of our time.

As you can see my concept of the engineer, at least for the purpose of this lecture, is in the center of the universe. The engineer brings with him a series of methodologies in analysis, design, and experimentation. We supply the engineer with certain inputs and he delivers certain outputs. These are shown in Figure 2.

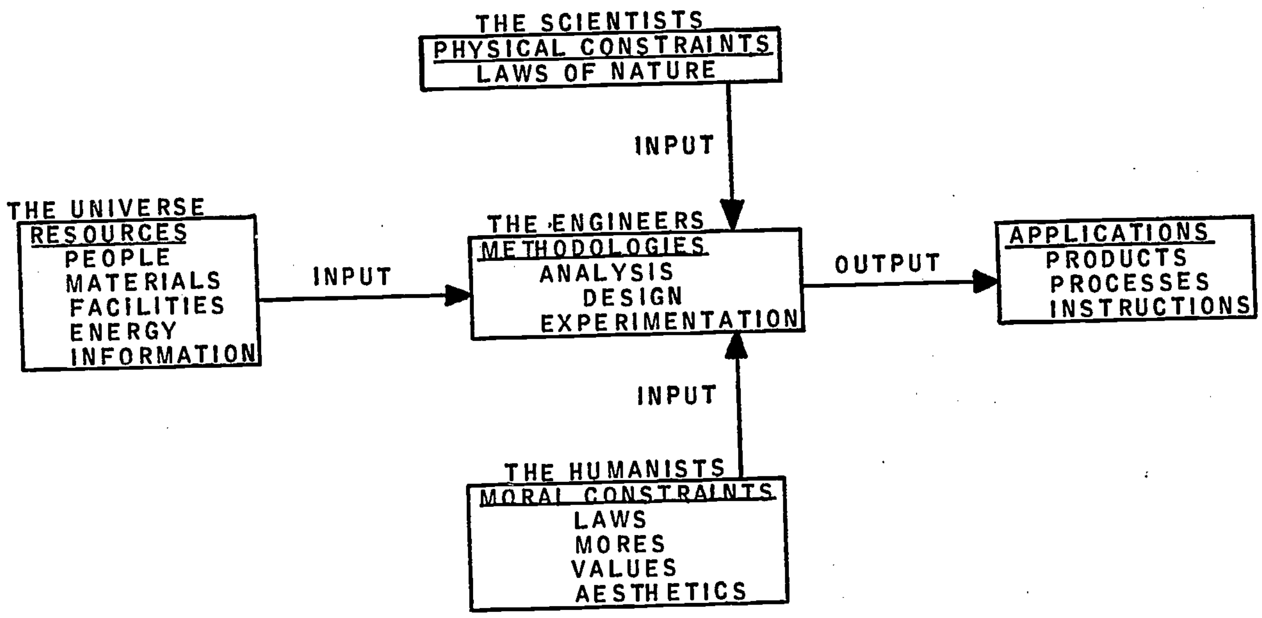

FIGURE 2 The position of the engineer, his supplies and tools.

Some of the inputs are resources: people, materials, facilities, energy, and information. You can name other things but these are very general categories. The engineer's role is to take these resources and to combine them with the physical constraints that we have in our universe, namely the laws of nature. These laws are provided by the physical and social scientists. They tell us why things happen, how they happen, and they serve as one kind of constraints on the kinds of things that engineers can do with the resources. Similarly, other constraints are the moral constraints: the laws of our society, the values of our civilization, our mores, music, art and our esthetic appreciation of various things. Somehow all of these ingredients blended together in a crucible which we call engineering, yield a whole series of applications or products. These can be physical things; they can just be a book, which has in it a set of policies which govern an enterprise; or they can be a set of instructions on how to operate something. All of these inputs are required to obtain these outputs. If I were to try to define an engineer, or what he does, or the aim of engineering, I would say that it is "to optimize the usefulness of the value of resources to man."

Let's talk for a moment about the system itself. Here is one possible way of defining a system. As a thermodynamicist I would usually define a physical system as "a region in space and in time which we define arbitrarily in order to obtain the answers to certain questions that we ask". There is not specific reason why we must define a system one way rather than another except that some ways make it easier to obtain an answer. In the analysis and synthesis of socio-economic systems, it is perhaps more appropriate to use the following definition: "A system is a set of resources (people, materials, facilities and information) organized to perform designated functions in order to achieve desired results." The most difficult thing to do is to set up the objectives. Quite often in our processes we do not do this. We start out saying we have a problem; we start working on it; and when we get to the end, we say what are we trying to accomplish. Since we do not have very good measuring sticks namely criteria to begin with we cannot tell how much progress we have made. Perhaps some of the new designs or procedures we have introduced are truly innovated and we are making progress in a positive direction (what ever that means). But without an explicit value systems to guide our evaluation process, a major component of systematic progress is missing.

The enormous numbers of scientific and technical advances by a basically affluent society has put us in a position to do many more things with the technological bits and pieces. Systems engineering holds the key because it is concerned essentially with devising operational systems and processes that meet human needs. The rationale for using systems engineering is that it helps us to get what we want. That's a very good rationale. But it should be remembered that the systems approach is a scheme for designing large complex systems and that it emphasizes the importance of the interrelationships which tie a system together into a recognizable entity. When we talk about socio-economic systems, we are talking about projects or programs involving millions of dollars and the lives of hundred of thousands of people. It would be inappropriate to utilize the methodology of systems engineering, with its accompanying allocation of resources and time, to the solution of very simple problems.

A final point which I would like to emphasize is that we cannot, given a specific problem or a set of requirements, arrive at one particular optimum kind of an answer. I think this point can be best illustrated by the following illustration. Assume that the Dept. of Defense has decided that it wants to build a supersonic airplane. It sets down some requirements: the plane must tarvel 2000 miles per hour; it must have a certain range; it must carry so many people; it must not cost more than a certain amount of money. These are just some of the quantitative requirements. The plane must also be comfortable, aesthetically pleasing, reliable, easily maintained and have a low noise level on take off. What should the airplane look like? In the design process, there are an infinite number of different possible configurations. It is the engineer's responsibility to select a few of these, look at them carefully, and then finally select one which will "best" meet the requirements. Then the engineering task is to try to optimize this one design configuration; namely, to make it come as close as possible to what the design requirements are. But in general, we cannot start out with the requirements and deduce "the" one specific answer. So it will be with educational institutions. Any of the techniques that we may develop will not be "the" answer, "the" way to do it. What we will come out with, is just one possible way based upon our own experience and our own tools.

There are procedures in designing a system and applying systems technology. Figure 3 summarizes a set of steps with which most of you are familiar. Whether you are a scientist, a social scientist, or physical scientist; whether you are in business or any other area where you try to do things systematically, there are certain fundamental general steps that we usually follow. They can be helpful in almost any problem in which you are designing something new or redesigning

1. *IDENTIFICATION OF THE NEED.*
   As a analysis of whether or not a need exists is required. Often a need, as originally stated, is not what is really needed to satisfy the final objective.
2. *INFORMATION COLLECTION AND ORGANIZATION.*
   All factors which relate to the system need to be considered. Where necessary, experiments must be devised to obtain data otherwise unavailable.
3. *IDENTIFICATION, STATEMENT, AND MODELING OFF SYSTEM VARIABLES.*
   All factors influencing the system—the so-called "boundary conditions". Engineering systems, subsystems and components can be analyzed into basic elements which, when described or prescribed in appropriate detail and when properly synthesized, will constitute the design of the system.
   a. INPUTS: Those resources and other environmental factors which are converted (or modified) by the system in question.
   b. OUTPUTS: That which is produced by the system.
   c. TRANSFORMING MEANS: Used to obtain the relationship between inputs and outputs.
   d. CONSTRAINTS: All elements and factors which express limitation and/or need to be accounted for in the design.
4. *CRITERIA DEVELOPMENT FOR OPTIMUM DESIGN.* The rules for judging relative merit.
   a. Development of Value Systems
   b. Criteria relationship among values
5. *SYNTHESIS AND ANALYSIS.*
   Evolving of systems to convert the inputs into the desired outputs. At this step only the requirement of realizability is usually met. Analysis forms the feedback loop around Synthesis.
   a. Physical Realizability
   b. Economic Worthwhileness (realizability)
   c. Financial Feasibility (realizability)
   d. Producibility
   e. Maintainability
   f. Reliability
6. *TEST EVALUATION, AND PREDICTION.*
7. *OPTIMIZING.*
   Optimizing (Maximizing the performance. Reduction to "best" system with available knowledge.)
8. *DECISION.*
9. *ITERATION.*
   It is recognized that the above operations are found throughout the design process. Many iterations will be taken around several or all of them. In particular the engineer continually re-examines his previous findings and decisions in the light of new information.
10. *COMMUNICATION, IMPLEMENTATION, AND PRESENTATION.*

FIGURE 3 Anatomy of design.

something which is old. The process is really an iterative process. All on the steps which I have enumerated here do not necessarily occur sequentially. Some of them occur sequentially, some are carried on in parallel, but most of the time you traverse all of these steps and then return to any one of them as the situation arises in order to refine what we already know.

The iterative steps in the refinement process reminds me of a story which I think is very applicable here. I think it will probably stick in your memory and that's why I will repeat it. The story relates to the question of how much do you iterate, or how many times must you repeat the design steps in order to solve a problem. Quite often the problems are so complex that people do not undertake them. They say: "there are many variables and we cannot control them; so let's not even begin." Or, some people say: "unless I can get a perfect answer, I will not begin." I believe that the engineer has a different approach and this story will illustrate it.

There has always been a question about the pecking order in our society. Physicists, or mathematicians usually look down their noses at people in engineering and people in engineering look down their noses at other groups of people. The question always is: is there any way in which you can test one group against the other to see which is better? A test was devised and carried out as follows.

A physicist and an engineer were placed at one end of a very long room. A beautiful girl was placed at the other end of the room. The contestants were told that the objective of the test was to see who will get to the girl first. The man who reached the girl first could "have" the girl. Well, there was very high motivation supplied in this test. However, there was a minor restriction in the rules of the race. After the starting gun was fired the rules required that each contestant must run half of the distance to the girl and then stop and count up to 10. Then he can run half of the distance that is left, stop, and count up to 10, and so on and so forth. Perhaps you recall the tortoise and the hare problem. This was a similar kind of a situation.

When the starting gun was fired, the engineer started out as fast as he could. He ran half the distance, stopped, counted to 10, and then he kept on running. The physicist didn't move; he just stood there. When he was asked why he was not participating in the race, the physicist replied: "I'm in the race, but I've already figured out that I'm never going to get there: so there is no point in running." When the engineer was asked why he was running he said: "I also did some figuring and I figured that first I would run half of the distance, then I would run half of that distance, and then half of that distance, and pretty soon, *I would be close enough* for all practical purposes."

I would say that he could also run half of the distance that was left if he felt that he wasn't close enough. In other words, he could keep on going until he finally reached whatever the desired goal was. You can get closer and closer to the objective but you must start someplace. You must make the first few steps. Each succeeding step will provide new experiences whch, in term, will facilitate the achievement of the ultimate objective.

The steps in the "anatomy of design" which are shown in Figure 3 were formulated by A. B. Rosenstein at the U.C.L.A. School of Engineering. The design steps are reasonably self-explanatory. They are typical of the steps that one would take

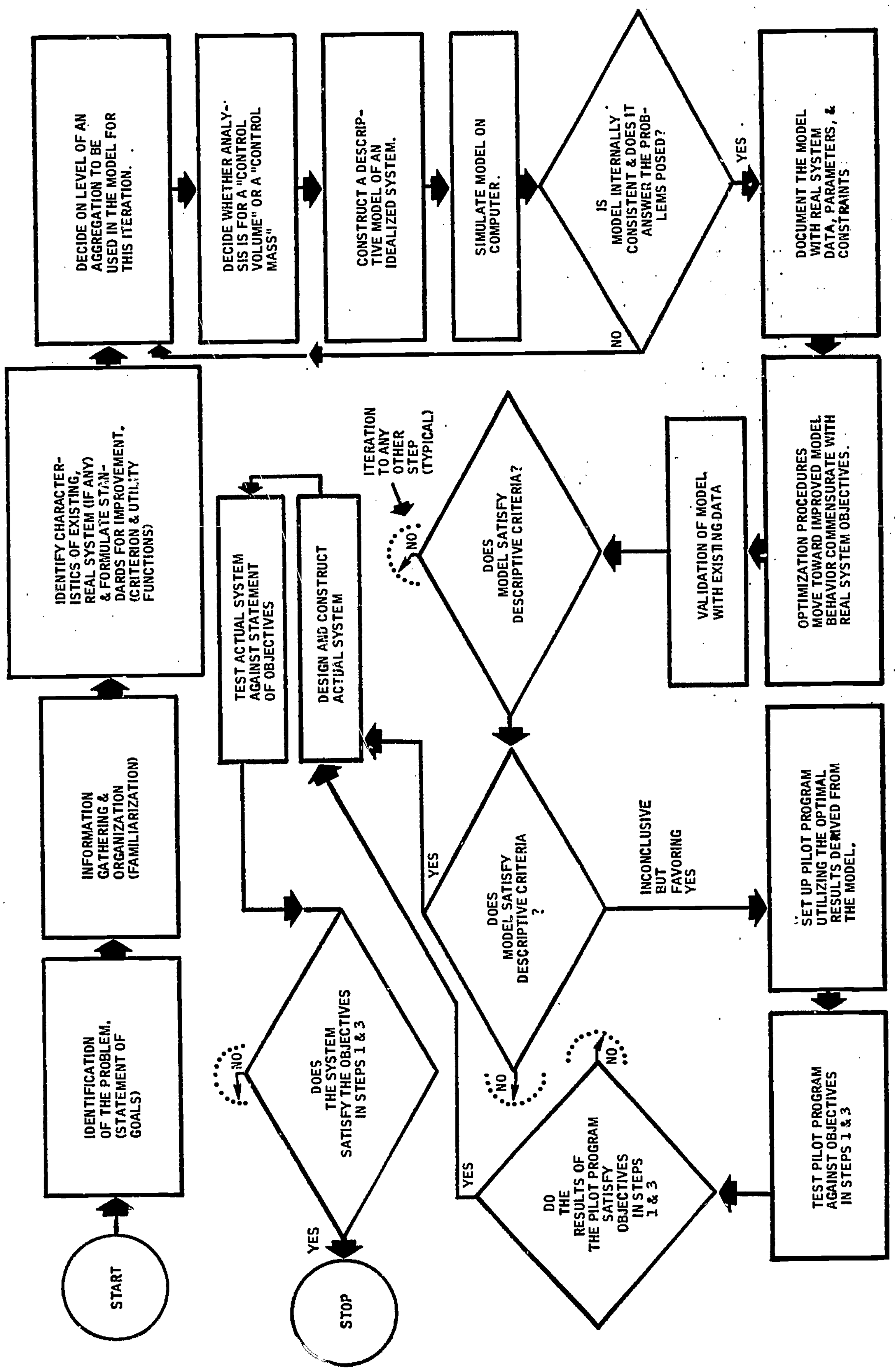

FIGURE 4 Generalized systems design procedure: A schematic representation of the iterative process.

during any phase of a large systems engineering project. The same steps could be used during a feasibility study, preliminary design, detail design, production, revision, or retirement phases of a project. These phases are often called the morphology (structure) of the design process.

Dr. Reisman and I, over the past few years have developed a somewhat more generalized way of stating the entire systems design procedure. A schematic representation of our approach is shown in Figure 4. It is necessary only to begin reading the diagram where it says "start" and to follow the various steps in the procedure until the instruction "stop" is reached. This is typical of the type of diagram which you will find in systems literature. It enables a systems designer to clarify where he is in the design process, where he should be going, to determine whether some crucial design steps have been omitted, and indicates whether his logic is faulty. With proper use, such a diagram can be a very useful tool in the analysis and/or synthesis of systems. Now let us turn to the systems analysis approach and then to its application in education.

The Systems Analysis Approach

The systems analysis approach requires that we view the system under study from the point of view of its inputs from and the outputs to the universe in which it operates and consider the feedback interrelationships along informational channels between the outputs and the inputs. Figure 5 the conceptual model of any system diagramatically integrates the above procedure. Table 1 discusses the various functions and/or attributes of the components in Figure 5 and also the various names used for similar components by writers or investigators in fields outside of education research.

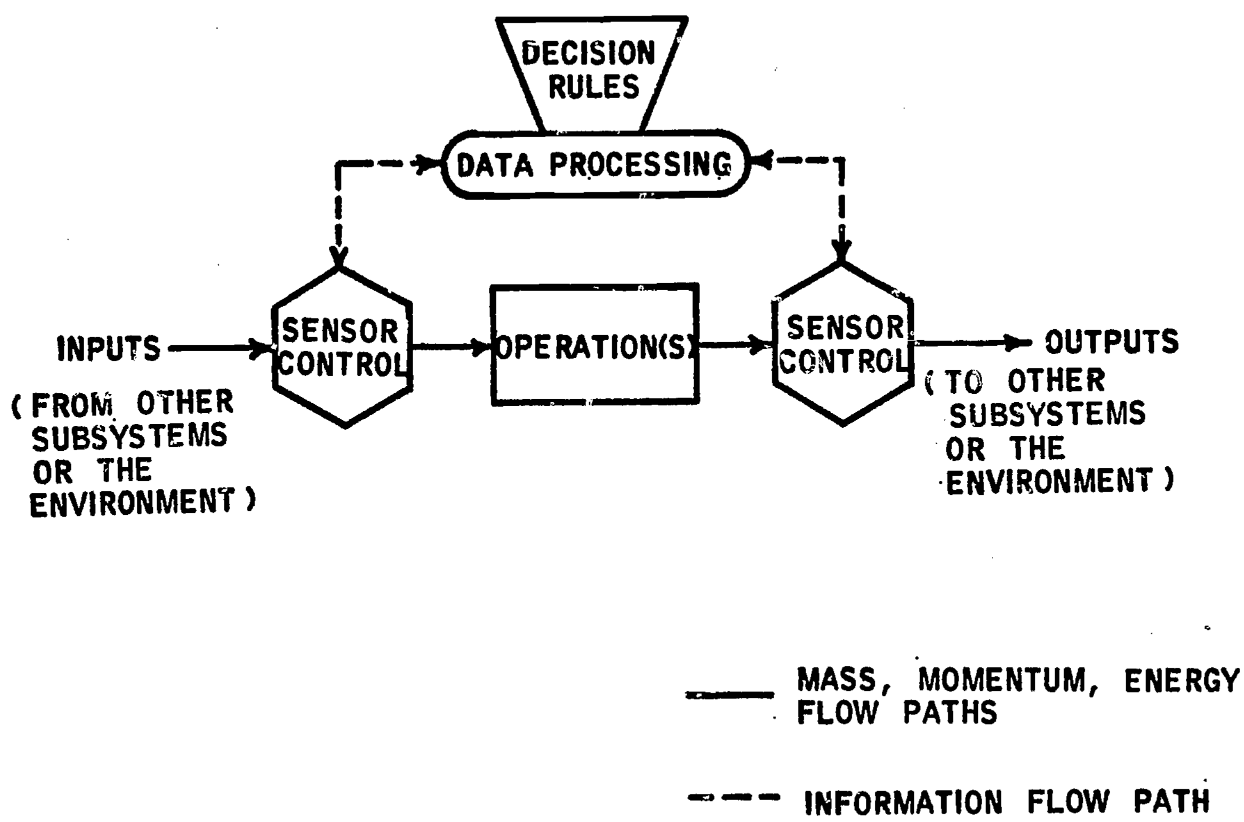

FIGURE 5 A conceptual model of a typical socio-economic system.

Component Symbol	Component Nomenclature	Component Functions
Operation(s)	System thermodynamics Activity (S. D. C.) Level (Forrester) Node (Reisman) Impedance)(electrical) Transducer)	Obeys the conservation concept for all mass, momentum, and energy flows: Rate of Input + Generation = Output + Accumulation. Examples: Source, sink, storage, any device, school, hospital, department, classroom, library, activity.
Sensor Control	Modulator (electrical) Controller (feedback theory) Valve (flow regulation) Instrumentation (property measurement) Transmitter)(info.) Receiver)	Measures or senses flow properties; transmits property data to data processing; receives control signals from data processing; controls flow rates, splits and directions. Links the mass, momentum, and energy flows with information flows.
Data Processing	Information processing system	Performs the following functions on information: Arranging, balancing, checking, coding, comparing, computing, converting, copying, counting, document writing, duplicating, filing, listing, posting, printing, proving, punching, reading, searching, selecting, sorting, summarizing.
Decision Rules	Controllers Management Administration Decision functions Control equations Policy	Provides rules, procedures, equations, algorithms, policies, and methods which relate the states (as represented by properties) in various parts of the system to each other and to the surroundings or environment.

TABLE 1 Symbols, nomenclature, and functions of components of a system.

From the aforementioned viewpoint, any system (and in particular socio-economic systems of the type represented by schools) can be thought of, to start with, as a set of black boxes. Into these boxes we feed various kinds of inputs, and we derive various outputs. The inputs can consist of the measurable properties of people, materials, facilities, and information. The same is true for the outputs. The sensor-controls indicated on Figure 5 act like valves which regulate the flow, and these valves carry out the additional function of measuring the properties of the flow. If the flow happens to be students, it would measure the student's I.Q., his aptitude, his previous grades, future aspirations, and so forth. This information regarding properties is conceptually transmitted to some sort of data processing system which integrates this information in a logical manner commensurate with the objectives of the system. The way in which this information is manipulted is controlled by a set of decision rules. These decision rules may be very highly formalized mathematical rules or equations or extremely informal sets of rules or procedures such as those by which people make decisions. In any event, considerable research has been done on decision rules. The rules control how the valves will operate to regulate flow-rates into and out of the system.

Any system must be considered in relation to the environment in which it is imbedded and the feedback between the system and its surroundings. The envionment is what governs the rates of change which occur inside the system. Hopefully, these rates of change are positive types in the sense that the system and the people inside it are constantly impr‹ ving upon the procedures that have gone by them in the past.

Applying the above concept to educational establishments, we turn to a generalized conceptual model for socio-economic systems developed by Dr. Reisman in his doctoral dissertation. However, his model has been somewhat revised, and it focuses specifically on educational establishments.

In Figure 6, therefore, we see the boundaries of the educational system having various subsystems such as operations, extracurricular programs, personnel training, and so forth. Outside of the system boundary are various subsystems with which the educational institution communicates either via channels of information or via actual channels through which physical flows (such as flows of people, materials, or energy) may take place. The external subsystems may consist of the student pool, financial pool, equipment or materials pool, and any number of others. Systems Development Corporation has developed a general simulation vehicle that permits a designer of an educational establishment to construct on a computer a detailed dynamic model of real or proposed high school organizations. This vehicle is a simulation and list-processing system consisting of a comprehensive set of procedures written in a special computer language known as JOVIAL.

The basic schematic diagram for a university, however, requires that Figure 6 be deaggregated (i.e. broken down into smaller systems or subsystems) in order for it to be useful in answering some specific questions which may be posed in a simulation. However, for the specific case of an educational institution, another approach to deaggregation has been found to be more useful. Before we can proceed with deaggregation, however, we must first look at the various major areas of personnel flows and interaction in a school of higher learning. Figure 7 conceptually outlines the various operational areas of the various groups operating in a school of higher learning, and it shows the major areas of overlay and interaction.

Thus, we notice the center core of Figure 7 as the area in which central

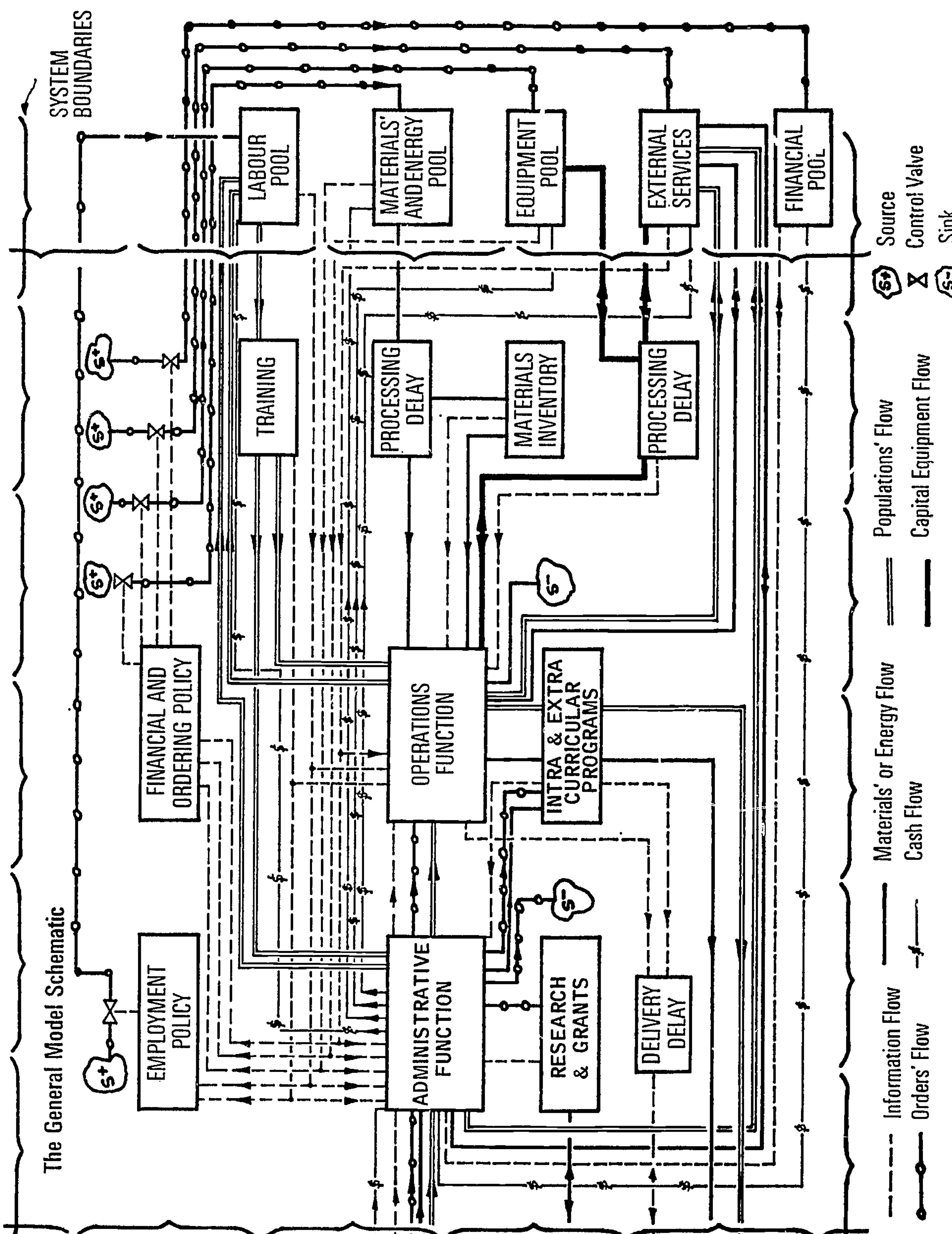

FIGURE 6 Generalized conceptual model for socio-economic systems developed specifically for educational establishments.

administration has sole responsibility. Surrounding the area of responsibility of the central administration is the area of faculty affairs responsibility, and the two, of course, show an overlap; and, therefore, mutual interaction. Next, radially we proceed to instructional activities, a major function of the college, and here

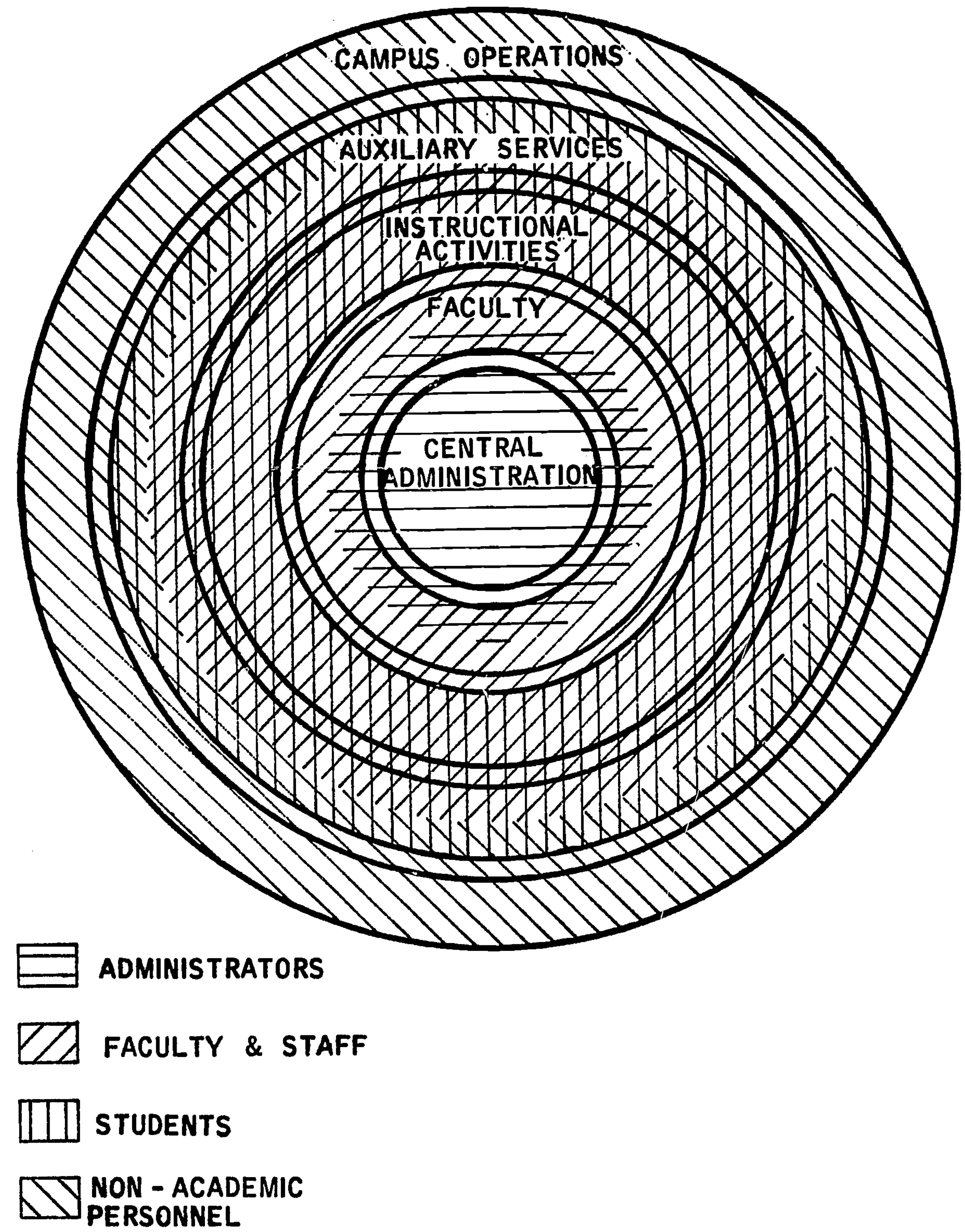

FIGURE 7 Major areas of personnel and interactions.

we again find overlap with faculty affairs as well as those of central administration. Next, we find auxiliary services overlapping with the functions preceding them, and we go on to campus operations. It is interesting to note that if the total system boundary had been drawn further out, there would be an obvious overlapping of the functions of campus operations with those of related services in the surroundings. Thus, the delineation of a boundary represents an arbitrary choice which is concentrated upon those areas of greatest immediate interest.

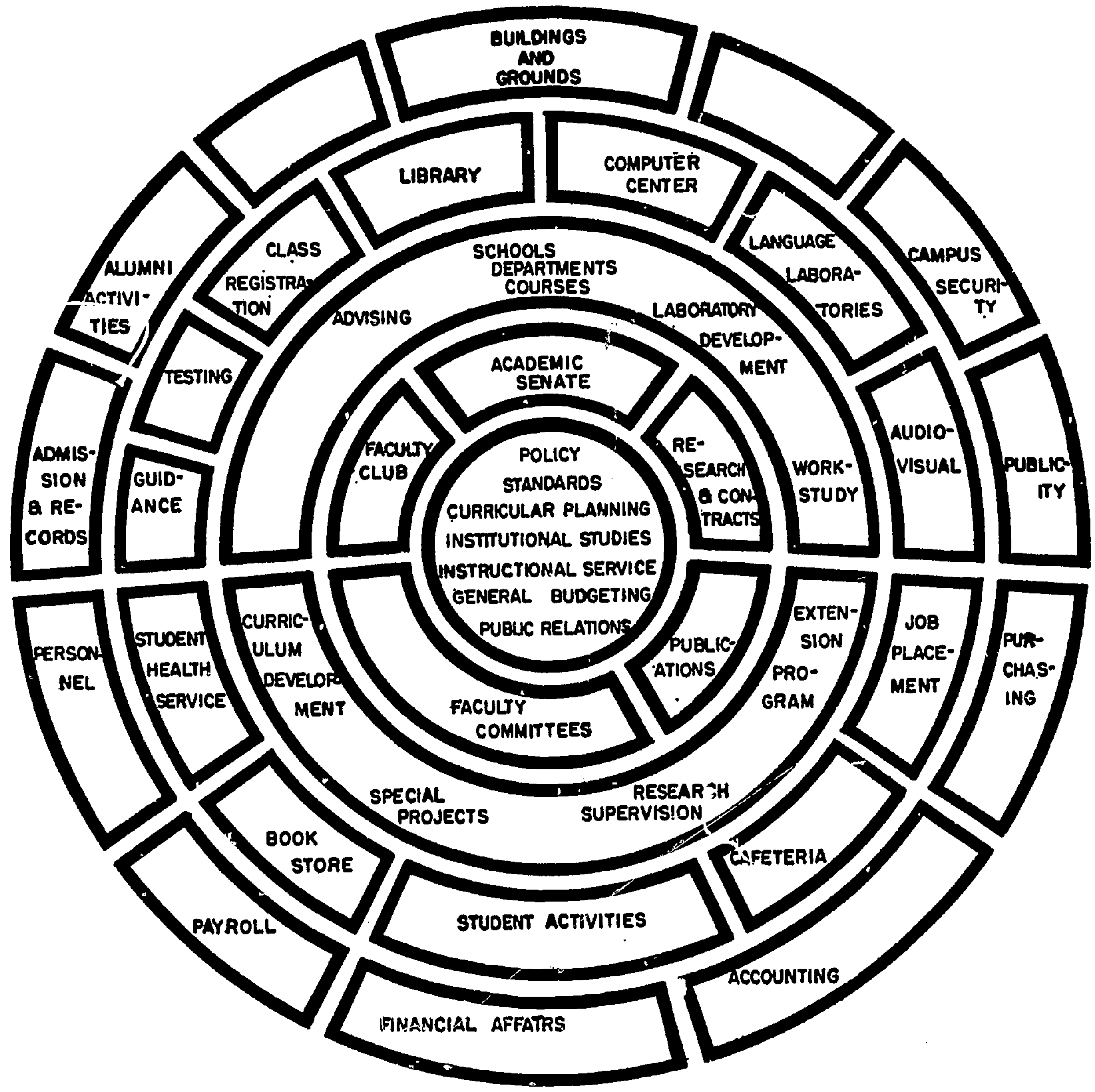

FIGURE 8 The major areas of responsibility in a college.

Each of these functional areas can now be broken down into more detailed functions. The manner of breakdown will, of course, vary from school to school, but the items indicated on Figure 8 represent what may be found in a typical college or university. Thus, central administration would be concerned with such items as policy making, standards, curriculum planning, institutional studies, instructional services, general budgeting and public relations. The faculty affairs area would include such items as an academic senate, the faculty club, research and grants, publications and faculty committees. It can be seen that central planning interacts very strongly with faculty affairs in terms of personnel and function. The instructional activity area can be conceptually broken down into such items as schools, departments, courses, laboratory development, work study program, extension program, research supervision, special projects, and advisement. It is in this area that the major functions of most colleges and universities are carried out, and the personnel that operate in these areas, namely the faculty and the students, are in very close interaction, and their actions overlap into faculty affairs and also into the area known as auxiliary services. The activities of the instructional affairs area are supplemented by auxiliary services such as the library, computer center, language laboratory, audiovisual aids, job placement, student activities, bookstores, student health services, guidance, testing, etc. And, finally, in support of all of the activities within the school are the campus operations. Included in the area of campus operations are such items as campus security, publicity, purchasing, accounting, payroll, personnel department, admissions and records, alumni activities, and buildings and grounds.

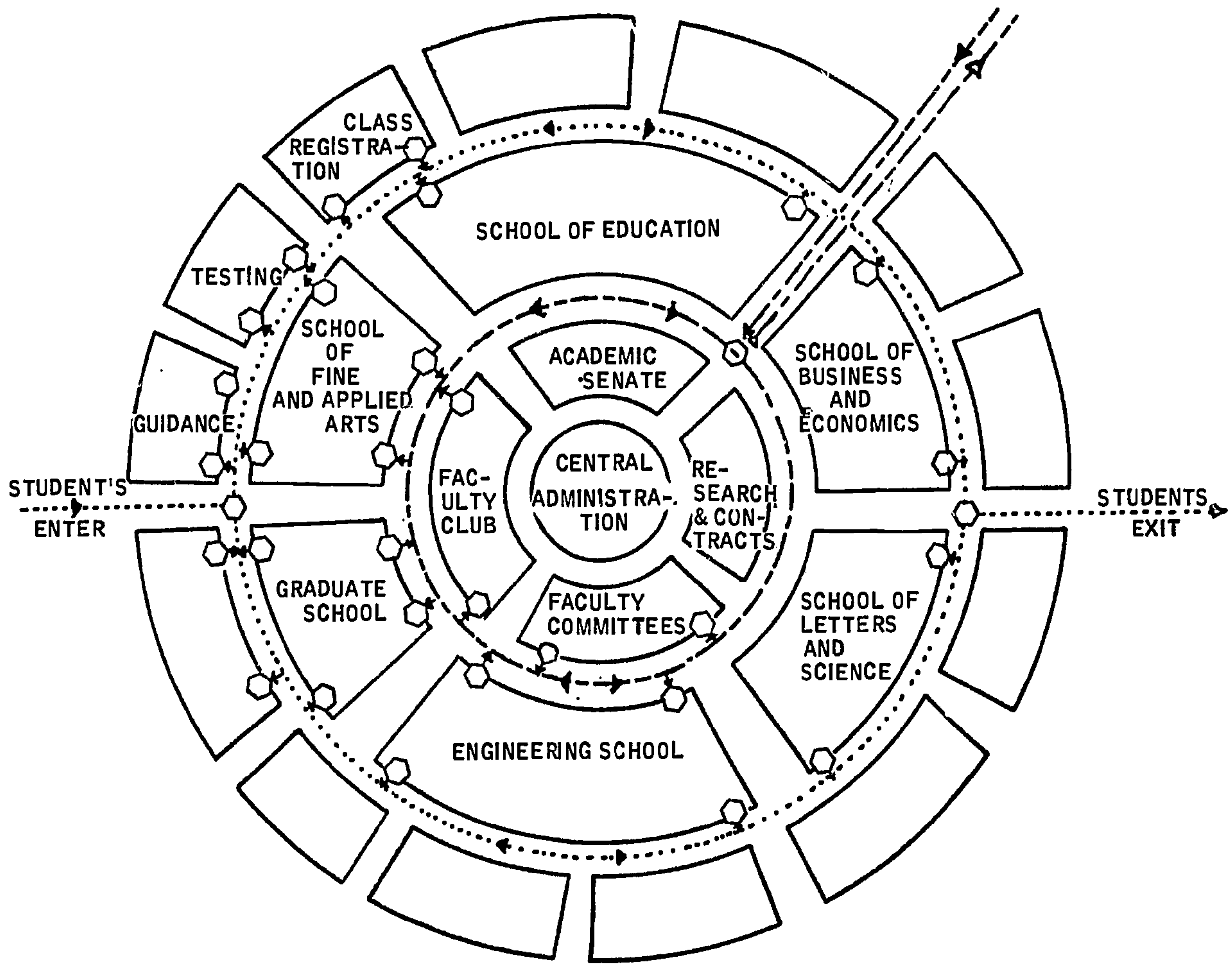

FIGURE 9 Functional areas and student flow patterns found in a typical college or university.

It is clear that each of the boxes represented on Figure 8 can and does represent by itself a subsystem of the entire system. Each of the subsystems interacts with all of the other subsystems. This implies that energy, people, materials, and information flows interconnect each box with every other box in the total system. It would be extremely difficult to draw all of the lines of flow, and for this reason, a conceptual way of keeping track of the various flow quantities has been developed. It will be noticed that between each of the major areas or functions of the school, there are corridors, and if we can imagine that each one of the corridors represent the locus of points of travel of any of the major items that are of importance in a school system, we find that our ideas about control of such a system become greatly simplified. In Figure 9 this idea is developed more fully.

If, in the course of an investigation, it is desired to follow the flow of students entering or leaving a school system, it is clear that a student would proceed during most of his time in school, along the corridor between the instructional activities and the auxiliary services. It is in this area and on both sides of it that we would expect to find students. Thus, a student can enter an educational institution and proceed to a guidance department, and then leave a guidance department and enter the testing department, and then leave testing and go to class registration, and from there cross the corridor and enter any one of the schools or departments and from there proceed to a library, etc. At any instant of time the student population may be found on the track inside the corridor or in any of the boxes on either side of it. If we impose sensor controls at the entrances and exits of every one of the boxes of areas of activity, it is clear that we can measure the student's properties both entering and leaving the system and thus have very precise control of flow rates and activities.

In a similar manner, if the center of interest lies with the faculty, it can be seen the faculty would usually be found in the next corridor between the instructional activities and the faculty affairs. Similarly, central administration people would be found in the innermost corridor, and clerical and other auxiliary personnel might be found in the outermost corridor in the diagram. It is not only conceivable but a usual thing in practice to find that some people serve a number of functions. A faculty member may also be a member of the central administration, or may also participate in auxiliary services of one sort or another. But, at any instant of time, each individual is carrying out a specific function or set of operations. If a person is attending classes, then he is a student. If he is at the same time serving in the capacity of a programmer, then he becomes part of the statistics related to auxiliary services, or auxiliary-service personnel. It is not very helpful to consider a person simultaneously in all of the capacities that he may engage in at one time or another. Usually, the mathematical equations for describing flow rates and properties will give systematic descriptions of a given quantity provided that such a quantity is not ambiguous.

Once the flow through the system has been conceptually delineated (i.e. a flow chart has been made of how each type of quantity such as population, energy, materials, and information flow from one point in the system to another), it is possible to apply the concept of conservation. The conservation concept is essentially an elaborate, analytical bookkeeping system for keeping track of various quantities that enter and leave a system or a subsystem. The mathematical equations for doing this are highly developed and have been applied in many areas outside the field of education. The analytical formulations are also susceptible to implementation on large, digital computers with various compiler languages such as MIMIC, DYNAMO, etc. At the present time, the size or complexity of the systems studies is virtually unlimited in terms of the capability of the computers available.

It should be recognized that although simulation languages or programs have been developed for application to industrial and socio-economic systems, few if any languages or programs have been developed for educational institutions. A notable exception, of course, is the high school simulation vehicle developed by the Systems Development Corporation. It is constructed in modular form so that models can be built up by assembling the modular parts (activities, procedures, packages, modules, and total systems) into a particular configuration. An extensive series of flow charts delineate all school functions operationally. Individual or batch flows can be accommodated by what amounts to an elaborate bookkeeping system.

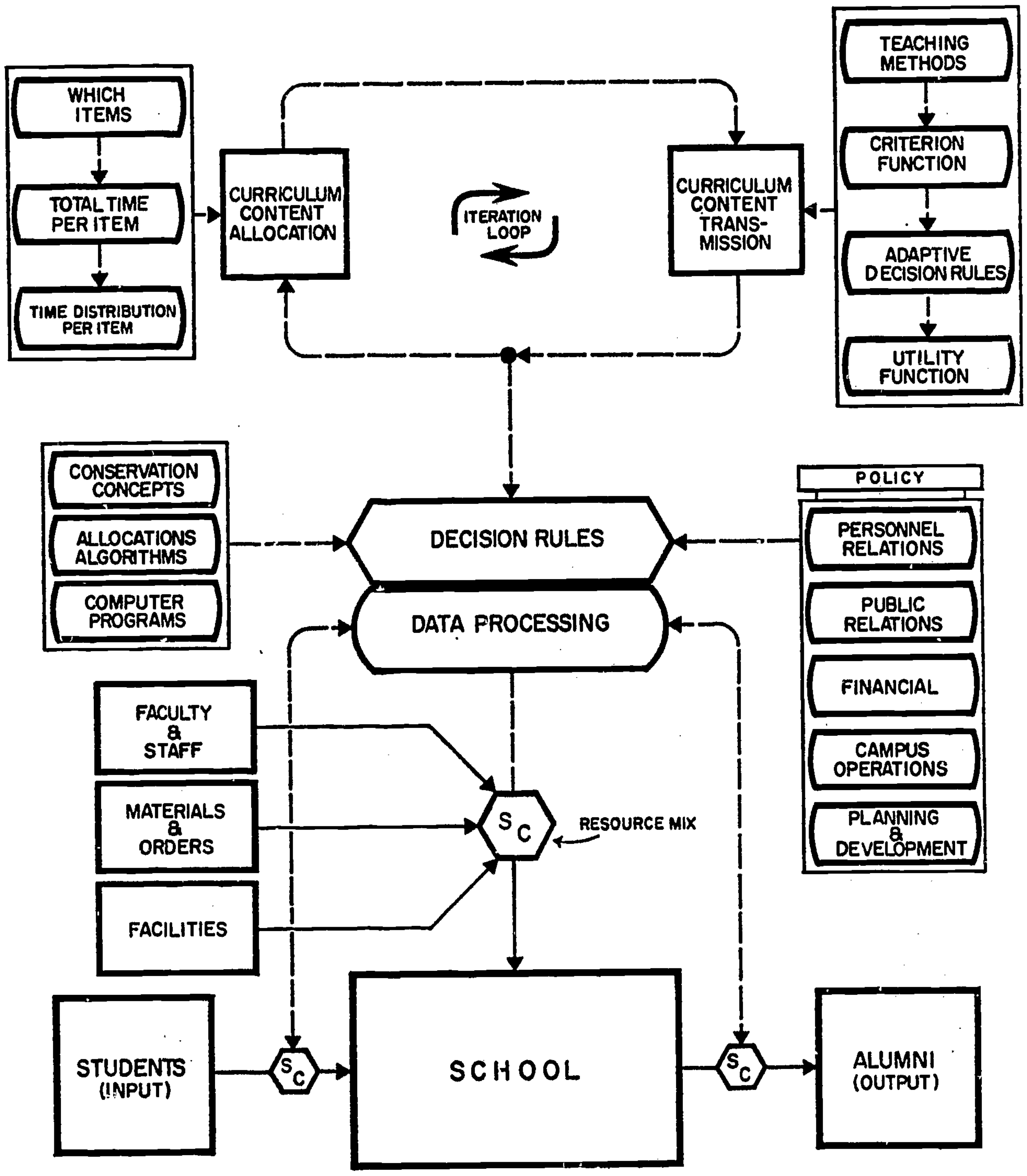

FIGURE 10 A schematic representation for systems analysis research.

The major flow parameters in a school are similar to those in companies or industrial establishments, but there are some significant differences, and these require a considerable amount of additional research before they become tractable.

A Conceptual Approach to Systems Analysis Research in Higher Education

Thus far, some of the tools for systems analysis in education were indicated. These tools may be applied to any combination of basic problems of interest in educational institutions.

The search for a unified way of thinking about research problems in education has lead to the development of the schematic representation shown in Figure 10. This diagram was designed to make it possible to systematically explore the various areas of research in education. Figure 10 is basically a more detailed version of Figure 5. It specifies the major inputs to the basic components of a school system.

The operations of an educational institution are determined by its educational objectives. From a managerial standpoint, the major objective of a school is to allocate available resources in such a way that the difference in educational potential between entering and leaving students is maximized. Students enter a school system with a given level of educational potential and, hopefully, leave with a much higher level. The central task of administrators is to allocate faculty, staff, material, facilities, and information at such times and places and in such proportions that the objectives of the school will be achieved in a most efficient manner.

The school which is shown in the diagram as a black box represents a highly complex socio-economic system. Students are the major input (raw material) of the system. Alumni, school dropouts, and transfer students are the output (product). Other inputs to the school are the faculty and staff, materials, orders (purchasing), facilities, and information. The exchange of information between the system and the environment is not shown on the diagram for the sake of clarity but it does exist. It is this exchange of information with the society in which the school is imbedded that makes the operations of the system meaningful. The larger systems that surround the school provide general educational objectives, curriculum constraints, limitations on funds, and other important inputs. The properties of all the inputs and outputs are constantly monitored by the sensor-controls.

The sensor-controls not only regulate the flows into and out of the system but also measure the properties, convert them into signals that are sent to the data-processing system and receive new signals which in turn determine new flow rates. The way in which the data is processed is determined by a large number of decision rules. These decision rules are, in the case of a school, determined by the faculty and school administrators.

As can be seen from Figure 10, the decision rules in an educational institution are derived from three major sources: the rules that are expressed explicitly by mathematical formulations, the administrative policies and procedures that are usually known to the faculty and staff in an implicit or verbal manner, and the curriculum. The explicit decision rules governing educational institutions are not as yet fully developed. The interrelationships between the various subsystems of a large social system like a school can be described mathematically by the application of the conservation concepts; namely, the laws of conservation of mass, momentum, and energy.

The development of allo· :ion algorithms, particularly those concerned with the allocation of funds and facilities has been a highly decentralized process in the United States. Although a substantial number of allocation methodologies have been in use by government and industry in recent years, few of these have been adopted by colleges and universities. Some techniques that have great potential usefulness for the growing and expanding educational institutions are those which optimize the relative locations of facilities (CRAFT); critical path techniques for planning and controlling personnel and financial resources (PERT); generalized financial models (CERBS); and Operations Research.

In contrast with the lack of integrated basic research in the areas of decision-making described above, a large amount of work has been carried on in the areas of educational data processing of student records and the scheduling of students into classes. Through cooperative efforts between industrial organizations such as IBM and educational institutions like Stanford University and Massachusetts Institute of Technology, a number of comprehensive computer programs have been developed and made operational. These computer programs are being used to supply data of all kinds at any time; to rapidly and efficiently carry on the multitude of activities related to school registration procedures, record keeping, grade reporting, and budget forecasting; and to produce master schedules for assigning courses, faculty, facilities and students.

Another large class of inputs to the decision rules of an educational institution consists of the administrative policies of the school. These are policies related to such items as personnel relations, public relations, finances, campus maintenance and operations, planning and development. These policies vary from school to school, department to department, administrator to administrator. Often, policies are formalized in faculty handbooks, administrative codes and committee minutes; but usually, they are contained in the minds of the people who are doing the work. As yet, few formalized procedures have been developed for systematically and economically gathering and compiling policy information so that it can be readily used in systems analyses and computer simulation of the educational system. The most significant input to the decision rules in an educational system, however, is the curriculum.

The Curriculum: A Major Input to Decision-Making

The curriculum, educational program, or program of study reflects the purpose and educational objectives of the school. It delineates the ways in which the student population is to be transformed while passing through the educational system. Hence it is concerned with the educational process; what is to be taught, how much, when, where, and how subject matter is to be transmitted. Curriculum synthesis implications constitute primary inputs to the decision rules which control the data processing and ultimately the operations of the entire educational system. Decisions regarding the allocation of faculty, staff, facilities, equipment, and services flow directly from a knowledge of the requirements of the curriculum.

In order to consider some of the research that recently has been carried on in the area of curriculum, this area will be divided conceptually into two parts; the curriculum content allocation and the curriculum content transmission. These two parts form an iterative loop as shown in Figure 10. Studies are made to determine what and when subject matter should be taught, then the teaching methods are studied, then original assumptions regarding time allocations to the subject matter are reexamined and revised, then the teaching methods are improved, and so forth. At any instant in time, the data regarding the current status of our knowledge of the curriculum can be tapped off from the iterative loop and supplied to the decision-making component of the system.

I assume that the great strides that have been made in teaching methods, such as programmed learning and team-teaching, are known to you. In the few remaining minutes of this presentation, I would like to focus attention upon the curriculum design aspect; a problem area in which I have personally made some contributions.

The curriculum content allocation problem has been studied intensively by the Engineering Department at UCLA during the past few years. The Educational Development Program has produced some meaningful and systematic procedures for determining the content of the curriculum and the amount of time that is to be devoted to each item to be taught. The proposed procedure for curricular synthesis involves the application of three criteria to the subject matter of the curriculum. The amount of time allocated to each instructional item, topic, or course depends upon its relevance to the aims of the curriculum (the criterion of relevance); the degree to which an item helps or reinforces other items (the criterion of generality); and to a lesser degree, the use that a given item makes of other subjects (the criterion of articulation). This procedure maximizes the relevance of the whole curriculum to the aims of engineering design. The procedure can be generalized to fields other than engineering by defining different categories of subject matter and by adding other criteria as deemed necessary.

This procedure, which has also been utilized in curriculum synthesis studies at the School of Engineering at Dartmouth College, provides a systematic and relatively objective methodology for determining which items should be taught and how much time to spend on each item. It does not directly consider the problem of how to distribute the presentation of each item in time, i.e. when should each item be taught.

The problem of when to teach an instructional item or more generally, the problem of optimum scheduling of subject matter, was the subject of my own Ph.D. dissertation. I showed that the integration of basic principles of learning and forgetting, derived from educational psychology, leads to the concept that the degree to which a student has mastered a course, topic or item in a curriculum is a function of the type of subject matter, the type of learner, the teaching method and the sequencing and type-distribution of the subject matter. A mathematical model which facilitates the construction of optimal and suboptimal schedules of subject matter was developed. The model is intended to be used to estimate the degree of student mastery of one or more subjects at the end of the course of study. It takes into account logical and time constraints such as prerequisites and maximum hours of classwork allowable per week. A heuristic solution technique requiring the use of a large digital computer yields an improved schedule for a given body of subject matter and a known time allocation for each item. A large digital computer program for implementing the scheduling model was developed and made operational.

Validation and refinement of the sequencing model will help to bridge the gap between curriculum theory and its practical implementation in the classroom. In the final analysis, the success of a given educational program hinges upon the ability of the faculty and administration of a school to schedule each student into sequences of courses which will maximize the student's educational potential on the day of graduation, minimize the rate of forgetting after graduation, and achieve the educational objectives of the school.

My closing point is that some of the techniques that we have developed in systems technology are, I believe, applicable in the field of education in the administrative and the curriculum areas as well as in any other areas that you might pick. It's now merely a question of getting sufficient cooperation between the engineer and the sociologist, psychologist, economics people, and educationists, so that we can translate some of the major known relationships into practice and develop systems far more optimal than they are today.

editor's prologue

The previous paper discussed the contribution that the engineering profession can make in the general field of education. We are now ready to focus on a particular aspect of education — the education of those who administer anesthetic or pain deadening drugs either in liquid or gaseous form to patients undergoing various surgical operations. The trainees in such programs might be medical doctors as would be the case with anethesiologists or other highly trained professionals generally referred to as anethetists. In either case the training programs require, in addition to a grounding in the theoretical aspects of the discipline, a rather extensive clinical experience. In the past and still today, the skills required by members of this profession are acquired right on the "firing line" so to speak — in the operating room. The novice first observes the practitioner and then is allowed, a bit at a time, to take over some of his functions all of this of course under strict and close supervision. This practice requires a large number of patients in surgery in the training of but one or a handful of anesthesiologists. It requires a large number of practitioners who are willing and able to serve as mentors. We will leave undiscussed the effects of mistakes by the trainees in these settings.

In short, the present modus operandi leaves much to be desired, yet, until the work described in the next paper there was no alternative approach available nor contemplated. We note here that an interdisciplinary team made up of educators, seasoned anesthesiologists and engineers has developed a training device which simulates much of this clinical experience at no human cost. The experience can be obtained around the clock by large numbers of trainees without requiring the presence of those highly trained individuals who are in such short supply today and will be in the foreseeable future.

Thus, for a look at the history and the capabilities of Sim I a "Link" type trainer for anesthesiologists, we turn to the paper by Professor Stephen Abrahamson.

A COMPUTER BASED PATIENT SIMULATOR FOR ANESTHESIOLOGISTS

Dr. Stephen Abrahamson

This is the story of the development of Sim One, a computer-controlled anthropometric manikin constructed to resemble as nearly as possible a human being and to function — as realistically as possible — as a human being when prepared for surgery by an anesthesiologist. Sim One had its origin in a conversation involving Stephen Abrahamson and Tullio Ronzoni, the latter at that time an engineer at Aerojet General's Von Karman Center. Mr. Ronzoni was also Chairman of the Committee on Diversification of the Los Angeles County Chamber of Commerce. He expressed the Committee's interest in exploring other applications of industrial potential in Southern California — that is, other than aircraft and defense industry. His question was quite simple: "How can we use computers in medical education?"

It was apparent early in our conversation that routine analysis of research data was not the answer to that question. Rather, we began to explore the possibility of computer-controlled simulation as a training aid in medical education.

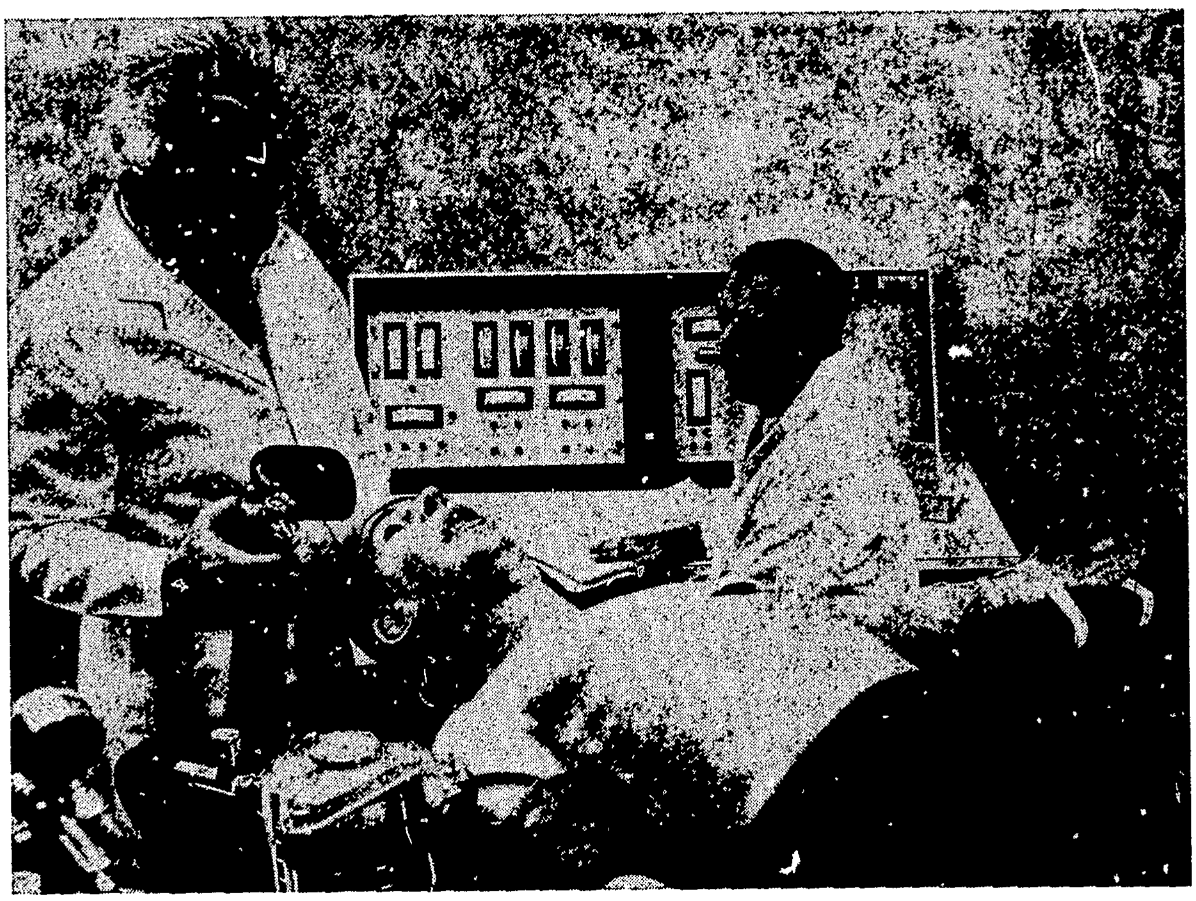

FIGURE 1 Dr. J. S. Denson (left) of the University of Southern California School of Medicine demonstrates revolutionary computer-controlled anesthesiology patient simulat-- while Aerojet-General Corporation Program Manager Paul Clark checks responses at the instructor's control console.

The role of an anesthesiologist seemed to me to offer the kind of situation that would lend itself to this application of computer sciences. The anesthesiologist must monitor many different life signs while his patient is undergoing surgery. He must monitor blood pressure, pulse rate, heart sounds, respiration, and the like. Thus, it seemed that we might be able to present an anesthesiology student with exact replications of the monitoring equipment and have these dials, meters, and gauges present information to him through computer-control. It seemed, further, relatively simple to present the student also with some kind of command console through which he could alter the conditions in response to the information which he read. For example, the student might notice a drop in blood pressure (in much the same way that he might in the operating room) and respond by calling for the administration of a certain dosage of a vasopressor drug. Computer response would alter the blood pressure information in much the same way that the administration of the actual drug to a real patient might produce such a change. By extrapolation, it was clear that different drugs, different gases, and different ministrations might all be programmed to produce appropriate reactions in the monitoring equipment — all under computer logic.

At this point, we consulted J. S. Denson, M.D., Director of Anesthesia for the Los Angeles County General Hospital and Professor and Head of Anesthesiology in the University of Southern California School of Medicine. Obtaining his enthusiastic support and interest, we then began planning with some of the engineers the Computer Sciences Division of Aerojet General's Von Karman Center. In these free-wheeling discussions, was born the idea that we could not only have the monitoring equipment (under computer-control) but also a plastic manikin to substitute for the patient, since much of the information the anesthesiologist needs and uses in the operating room comes from direct observation of his patient. The plan grew to include a skin-colored, skin-textured body capable of simulating breathing, heart beat, pulse, blood pressure. In addition, it would have a life-like appearance externally and the interior of the mouth and throat were to be realistic.

Following many frustrating attempts to obtain financial support for this project, we succeeded in interesting the United States Office of Education's Bureau of Research and through their Cooperative Research Project we obtained $272,000 for a two-year project, beginning January 1, 1966.

Thus, in January, 1966, we began our developmental work in the January, 1967, "Sim One" came off our personal production line. After some initial testing, this model of Sim One was returned for certain changes and new skin. In March, 1967, a second product was delivered for testing. This, too, was studied and returned for further modification. In June, 1967, the final version of Sim One was delivered and is now in use.

The maneuver chosen to test the feasibility of this kind of simulation was the insertion of a tube into the larynx (endotracheal intubation). Insofar as possible, Sim One is capable of "behaving" exactly as a normal patient in response to what is done to him by the anesthesiologist. Roughly, then, the simulator is capable of acting in a life-like manner in the following ways.

Sim One breathes in a realistic fashion: there is both motion of the muscles separating the cavity of the chest from the abdomen (diaphragmatic motion) and chest-wall motion. The rate and amplitude of breathing can be varied and such changes can be noticed by an observer. Sim One's eyes open and close in a normal manner and the pupils of the eyes are capable of dilating and constricting—although not in response to light stimulus in this model. Sim One has a heart beat and temporal pulse, both of which are synchronized with the heart beat. The rate and amplitude of heart sounds can be varied and, indeed, both the quivering of the muscles of the heart chambers (ventricular fibrillation) and one alteration in the rhythm of the heartbeat (arrhythmia) are possible in Sim One.

FIGURE 2 Sim One Project Co-Directors, J. S. Denson, M.D. (with anesthesia mark) and Stephen Abrahamson, Ph.D. (at instructor console), of the University of Southern California School of Medicine, check operation of computer-controlled patient simulator known as Sim One.

Sim One "lies" on an operating table with his left arm extended and arranged with an intravenous portal, allowing the injection of simulated drugs. On his right arm is a blood pressure cuff attached to a manometer. Sim One's mouth opens and closes; inside are teeth, tongue, epiglottis, aryepiglottic folds, and vocal cords—all quite realistic in appearance.

In endotracheal intubation, the following steps are taken. These steps are taken, therefore, in the case of Sim One. At the outset, oxygen is administered through a mask for a period of five minutes. Oxygen flow and the amount of oxygen that gets through to Sim One are monitored by the computer and appropriate physiologic changes—according to these amounts—are produced in the simulated respiration and circulatory system. Following this, there is an injection of sodium pentothal, a drug to put the simulated patient in a state of unconsciousness. Both what the drug is and the amount administered are sensed by the computer and the appropriate simulated physiologic response is then dictated. That is, approximately 20 seconds after the injection of a sufficient amount of sodium pentothal, Sim One's eyes close and unconsciousness is simulated.

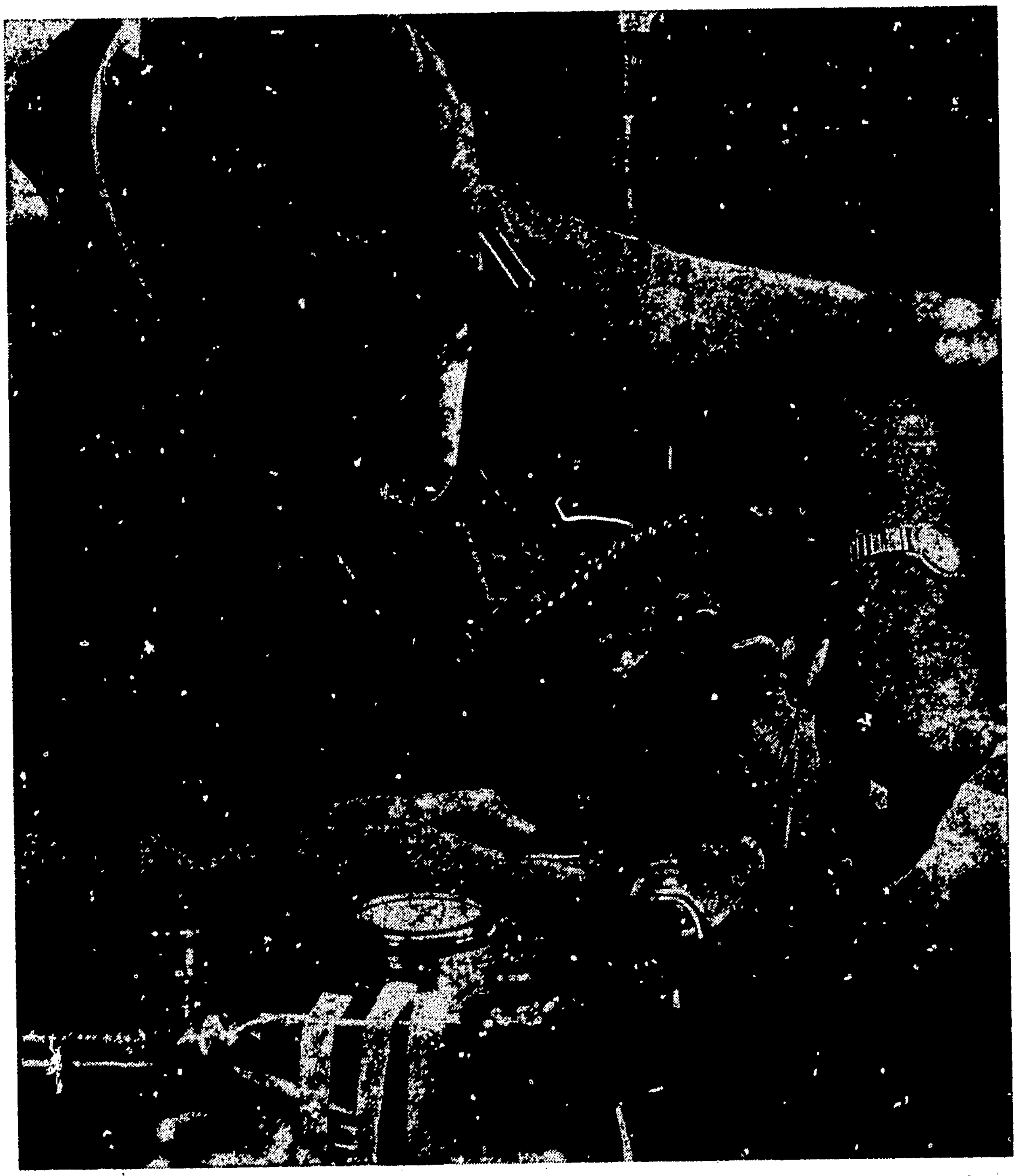

FIGURE 3 Computerized Sim One and anethesiologist working together under simulated operating conditions.

At this point, the anesthesiologist administers another drug, succinyl choline, a muscle relaxant which causes all of the muscles of the body to stop functioning with the exception of the heart. In the case of Sim One, again the computer is able to sense the drug and the amount of the drug and produce appropriate simulated physiologic responses: as the succinyl choline become effective, Sim One's breathing stops and he is ready for intubation. Incidentally, succinyl choline in a human being has a tendency to stimulate certain nerve endings just prior to its paralyzing effect. This stimulation produces minor muscle fasciculations. In Sim One, these fasciculations can be seen in the area just over the collar bone.

Now Sim One is ready for intubation. The anesthesiology student next uses an instrument to examine the interior of the larynx (laryngoscope) to facilitate insertion of the airway tube. Following the insertion of the tube, the intubation maneuver is completed with the removal of the stylet which holds the airway tube rigid for insertion purposes, use of a bite-block to prevent the simulator's clamping down on his own airway, inflation of a little rubber cuff surrounding the airway to seal the point of entry, and attachment of the hose which will bring oxygen and nitrous oxyde from the anesthesia machine. With all of these things accomplished, the anesthesiology resident can now "breathe" for Sim One by squeezing the reservoir bag through which the mixture of gases is sensed by the computer and appropriate physiologic responses are dictated through the program.

What has been described so far is a "normal" run. In addition, Sim One has the capability of introducing problems for students. These are patterned after real problems which may arise in some instances in the operating room. On instructor command, blood pressure can be increased or decreased as a problem for the student. In addition, heart rate can be increased or decreased and, indeed, a stoppage of the heart from functioning (heart arrest) can be introduced by instructor command. The rate of breathing can be increased or decreased as a problem for the student.

In the case of any of these changes, appropriate physiologic responses are governed by computer logic: for instance, if the breathing rate is significantly reduced, Sim One will begin to show signs of insufficient oxygen. Heart arrest, if not detected and responded to, can lead to "death" of Sim One.

Other kinds of difficulty can be introduced. Sim One can be instructed to vomit; obviously such a condition would pose a serious problem. Suction is available in the simulated operating room just as it is in the real operating room. Sim One regurgitates through an esophageal opening and the fluid collects in the oral cavity. The student must use suction to remove the vomitus before it occludes the airway or gets into the bronchial tree.

On instructor command, these other difficulties can be introduced: (1) Spasmodic closure of the larynx (laryngospasm), (2) a blocking of the airway from the trachea to the left lung or that to the right lung (a left bronchus block or right broncus block), (3) increased jaw tension, (4) ventricular fibrillation, (5) heart arrest, (6) an alteration in the rhythm of the heartbeat either in time or forces (arrhythmia), and (7) "bucking," a spasmodic motion of the manikin's trunk, simulating an effort to reject the airway tube in the total anesthesia becomes too light.

The instructor console includes the means of monitoring the following informaiton.

1. Systolic blood pressure.
2. Diastolic blood pressure.
3. Heart rate

4. Oxygen flow rate
5. Nitrous oxide flow rate
6. Total ventilation rate
7. Which drug is being administered intravenously
8. The drug dosage being injected
9. The effective drug dosage in the simulated blood stream
10. The distance the airway tube is inserted

In addition, the instructor console provides certain signal lights to alert the instructor of the following things.

1. Heart arrest
2. Proper attachment of the anesthesia gas mask
3. Proper seating of the mask on the manikin's face
4. Proper attachment of the airway tube
5. Proper inflation of the cuff surrounding the airway tube
6. Out-of-phase assisted ventilation
7. A pinched lip

At any point in the program the instructor can stop what is taking place by placing the simulator in a "hold" condition. That is, everything can be halted while the instructor works with his student or reviews with his student things that have taken place. At that time, the instructor can either start the program again from the beginning or continue it from that point. In addition, the instructor can call for a print-out at any point during the program or at the end of the program. The print-out contains a chronological list of all of the actions taken by the student, the instructor, and the simulator itself along with a notation of elapsed time from the beginning of the program for each of these actions. Finally, the analog computer component provides a strip recording of the following parameters.

1. Systolic blood pressure
2. Diastolic blood pressure
3. Pulse rate
4. Oxygen level
5. Carbon dioxide level
6. Ventilation
7. Lung displacement

Sim One represents the product of some of the most remarkable team work ever achieved. All of the physiologic data, the pharmacologic principles, the anatomic structure, and principles of anesthesiology were supplied by J. S. Denson, M.D., Professor and Head of the Division of Anesthesiology of the University of Southern California School of Medicine. The information thus supplied by him had to be understood by the engineers at Aerojet General's Von Karman Center before they could transform the information into suitable mathematic form. The engineers visited the operating room and witnessed surgery involving the anesthesia technique of endothracheal intubation in order to familiarize themselves with the total processes involved. In addition, they studied physiology and anatomy at least to the extent of learning the language. Likewise, personnel of Sierra Engineering Company, responsible for the structure of the manikin itself, visited the operating room and observed surgery in process. At one point, a plaster cast of the interior of a trachea had to be prepared and delivered to Sierra Engineering Company. Involved in the activity were members of the Department of Pathology of the University of Southern California School of Medicine. Of course, the total project also required "input" from education and educational psychology as well as consultant services from physiology, chest medicine, and pharmacology.

By the time the simulator was delivered for its first tests, the computer program included uptake and decay curves for sodium pentothal, succinyl choline, and two vasopressors, Furthermore, if any of these affected the action of another, the program reflected that as well. Moreover, the physiologic response to varying amounts of oxygen and nitrous oxide were also programmed—and once again interaction among these agents (and with the intravenous drugs) was programmed properly.

Many kinds of problems had to be solved by the engineers in this developmental period. The simulator had to be capable of sensing what drug is being injected: the intravenous portal contains a coil and each needle is magnetically coded so as to provide immediate information to the computer as to which drug is being injected. The fluid injected then displaces a piston and is retained until the needle is withdrawn at which time the fluid is released into a receptacle. In this way, the computer can sense how much of the drug has been injected. The dosage then can become part of the instructions.

The educational benefits of Sim One are quite extensive. Ordinarily in the training of anesthesiologists, the beginning resident must get his training on whatever patient material is at hand. Thus, it is conceivable that a beginning resident might encounter very complex and troublesome patient problems in his early days of training. The use of the simulator makes possible a planned and gradual increase in difficulty of problems to be faced and solved by students. Thus, it is possible for the faculty to be sure a student is *ready* for something more difficult by having him demonstrate proficiency first in the less complex problem situations.

Using the simulator allows possible repetition far beyond the capabilities of any hospital in the country. Not only is it possible for the resident to perform several intubations even in the course of an hour, it is also possible for him to concentrate on any single phase of the process that has made it difficult for him as an individual learner. For instance, a resident who has difficulty learning to pass the airway tube through the vocal cords may practice only that part of the total intubation procedure over and over until he is confident that he is doing it properly.

Still another educational advantage lies in the "feedback" available immediately to the student and the teacher. By "feedback" is meant providing information to the learner concerning how he is getting along in his learning tasks. The printout and strip recording provide objective and accurate information concerning everything the student has done and all that happened in the total process. This information can be provided to him immediately upon command.

Still another advantage to the use of the simulator lies in the possibility of having each learner proceed at his own individual rate. A student who needs time on the simulator in order to perfect parts of the skill process involved can be told to put in practice. The student, however, who has mastered the processes is able to demonstrate this on the simulator since greater objectivity is possible through careful study of the computer-based information on the printout.

Ultimately, the investigators feel confident that a significant saving of faculty time can be achieved not only in the use of the simulator for training anesthesiologists residents but in the use of similar simulators in the training of other kinds of health care personnel.

Even in the limited application itself thus far, residents have used Sim One without faculty supervision on many occasions.

There are, of course, other contributions. The use of Sim One (or, in fact, any patient simulator) abviously makes it possible for beginning students to learn basic skills without involving live patients. Thus, potential discomfort or even harm may be spared patients. Coincidentally, of course, this must contribute to the time-saving factor since the beginning students' contact with patients is always very carefully monitored and his attempts are always very brief and frequently interrupted by the instructor. Extending the simulator concept from Sim One to the many other kinds of patient simulators possibly can introduce still more caution into the training of health care personnel.

One of the future applications of patient simulators will lie in systematic study of health care skills. Through the use of simulators, it will become possible to study more objectively and more systematically the performance of virtually all manual skills required in patient care.

Finally, the simulators will make possible the systematic study of training necessary for people to perform the many tasks in health care. The synthesis of these two sets of concurrent systematic studies may also lead us to a better understanding of the kinds of health care personnel that might be needed in the future.

The future work in this area depends upon continued support, obviously. At this stage of work, further refinement of Sim One itself is the first step. Sim One must be moved to allow for a larger variety of training activities to take place. This in turn will permit a more thorough evaluation of the educational contributions of patient simulators.

Ultimately, we believe that the other kinds of simulators can be developed and tested. Patient simulators might be employed in any instance in which health care personnel must perform endoscopy or manipulation. In addition, whenever health care personnel must monitor through listening, observation, or palpation, simulators may be employed to speed the training process and provide experience for beginning students thus sparing real patients from possible discomfort. Indeed, we are just at the threshold of an era in the use of such simulation in education.

editor's prologue

Dr. Lindvall, in his paper, attributes to Arnold Toynbee a sensing of the mood of some of today's youth. "They are beginning to look into some of the social problems which technology may have created and is not solving." A major such problem, in the technologically developed nations, though physical in nature has many social ramifiactions. This is the general problem of pollution of the environment in which we live and in particular the pollution of our air and of our waters. The observations of David Hume as outlined again in the Lindvall paper are quite appropriate here. "Politics considers men as united in society and dependent upon each other." Technology, as indicated by Dr. Lindvall, has had a great impact since the days of Hume "in uniting men in society and increasing their interdependence." "Bridges are," in fact, "built, harbors opened, canals formed; fleets equipped; and armies disciplined." However all these actions by society do not quite require the breadth nor the depth of concerted actions as is, at this stage, required in the control and abatement of pollution of our environment. We, therefore, are in need of political visionaries who have the sense and the power necessary to convince society at large to do something concrete and meaningful about the problem. Until now the politician; the manager; as well as the engineer has sought in Hume's words "a pretext to free himself of the trouble and expense and" . . . have layed . . . "the whole burden on others." Time is running out on us in these matters; "in the implementation of the vastly expanding science in an anxious world, the engineering profession must enlarge it's concept of it's role." The last quote we had already seen in the first paper- of these proceedings. The next paper by a respected and concerned political figure will discuss the problem of pollution, the extent of its damage and irreversibility and contribution that can be made to society by the profession of engineering.

AIR AND WATER POLLUTION CONTROL AND ABATEMENT: A SYSTEMS APPROACH

Senator Gaylord Nelson

Interested and concerned citizens, I appreciate very much the opportunity to come here this evening and participate in what is obviously a very useful, constructive and fruitful exploration of some of our environmental problems.

I see on the program that it is asserted that I will speak on some of the political aspects of pollution. I could spend a whole week on the political aspects of doing something about the environmental problems that face us. I think that the environmental crisis in this country is a dramatic example of a political failure, since the problems that confront us are not, in my judgment, to be solved without political action. It is in the political arena that we will or will not resolve the problems of environmental deterioration, environmental pollution. Of course you have to have the scientific knowledge and the engineering knowhow; and you have to have the research; and you have to have all kinds of other things. But the fact of the matter is, the problem will not be solved by private enterprise, or by individual actions or in any such way. As a matter of fact, in the past we left it to local governments, who didn't do anything, and we left it to private enterprise, and they didn't do anything. This is dramatic testimony to the failure of that policy when we see what has happened to the quality of the environment in this country. Today the Federal government is intimately involved, and I would hope that the local governments and state governments would become more intimately concerned and involved with all types of pollution control and abatement. We are speaking here of air pollution, water pollution in short, the whole issue of environmental pollution.

In order to understand more clearly the magnitude of the problem, I think it is important to look into the historical aspects of the problem and try to understand how we have gone about creating the mess that we are all in today. Early settlers in this country found themselves faced with a bountiful land, with clean water, abundant wild life, clear fresh air, apparently unlimited mineral resources and majestic forests. Almost immediately they began to destroy the land. The land was cleared and farmed for a few years and then the settlers moved on, leaving the land open to erosion. Beyond that, much land was cleared that never should have been cleared. Fur trappers roamed our great north country and decimated our wildlife populations. Soon the lumbermen moved in, clear cutting irreplaceable stands of virgin pine, firs, and hardwoods, with no thought of sustained yield or reforestation or protecting the barren land from erosion.

Because the nation had been blessed with such extensive resources, the effects of this pillaging was not felt or recognized for many many years. There were of course exceptions — a handful of very perceptive people whose names are well known in the world of conservation did sound the alarm but the pattern was established. Nobody ever stepped in to take any steps to control the destruction of the resources until it was too late and the damage had already been done. This whole tragic history of resource mismanagement demonstrates the fundamental necessity of governmental participation in resource management decisions.

With the 20th century came the industrial revolution. Factories sprang up everywhere, many of them depending on our natural resources. Industries, just as municipalities and cities used our sparkling clear streams as sources of power, of water and as sewers. Factories in cities constructed huge smokestacks which belched noxious fumes into our beautiful clear air. Coupled with this dramatic and industrial growth was a tremendous technological revolution in agriculture. We developed new hybrid seeds and high analysis chemical fertilizers, we built new machines to harvest our bountiful yields; and we developed pesticides to control the weeds and the insects and to insure our harvests. The consequence of all of these developments we cannot yet estimate in terms of the disturbance of the ecological relationship of the living things on the land.

Today America stands at the forefront of the world. Our industrial and agricultural capabilities are unequalled, our people are prosperous, our society has become affluent or effluent depending upon whom you talk to. The price we have paid for this is very high, much higher than we could afford. Much of our once abundant natural resources are almost gone. There are very few bodies of unpolluted water left in this country. Even our greatest fresh water bodies, the Great Lakes, are well on their way to final and total destruction. A recently released report on pollution in the Mississippi and Minnesota Rivers around the Twin Cities revealed disasterous pollution in those waters. Municipal sewage plants on the upper Mississippi discharge 208 million gallons of sewage into the river each day. Contained in this sewage are oxygen consuming wastes, equivalent to the raw sewage from a population of 1,200,000 people. This is the daily discharge into that river in the upper Mississippi around the Twin Cities.

Scientists and engineers estimate that air pollution does about 12 billion dollars worth of damage a year. The total national expenditure on air pollution control including the efforts of industry is estimated at 500 million a year. In other words, we are spending ½ billion dollars a year to attack a problem that is costing us 12 billion dollars a year. Automobiles alone are discharging each day enough carbon monoxide to pollute a blanket of air 400 ft. thick, 6 miles wide, stretching from New York to Los Angeles. Our coal burning furnaces discharge each day enough sulphur dioxide to pollute a similar blanket of air 400 ft. high, 15 miles wide from coast to coast again, every 24 hours. And of course the pollutants remain in the air currents and travel around the world.

All the concern about pollution that has been expressed in recent years has served to create a beginning of an awakening public awareness of the problem. Awareness, however, does not mean action. What will it take to make people act? Probably nothing short of a major environmental disaster. Last fall, New York City was enveloped with a choking smog for several days because of a strange quirk in the weather patterns. It ended with relatively little damage, but who knows what would have happened if the smog had lasted another 48 hours? There have been other occasions during which we have flirted with major environmental disasters, and one of these days we will have one.

Certainly the change of the challenge of pollution abatement is one of the greatest facing all levels of government today. It seems to me that it is the responsibility of our government to develop programs which will not only resolve existing problems but also will help us to avoid future crises. We cannot afford to wait until we are faced with a disaster before we move into action. The Senate Public Works Committee has reported out favorably the Air Quality Act of 1967. The passage of this act will definitely be a step in the right direction. There are many provisions in it which will serve to develop an effective unified program to fight air pollution. The Bill requires each state to submit to the Secretary of Health Education and Welfare air pollution standards for their particular state and plans to abate their existing air pollution bound areas. These standards and programs will be subject to approval by the Secretary of the Interior. The air pollution problems are not local, they are regional, nationwide and even worldwide. The new Bill will establish regional air pollution control centers. This means that those areas which have similar problems due to similar climatic patterns and similar geography will be able to work together to solve their problem. Most importantly the new Bill will provide more Federal money for the fight against air pollution. The bill provides a total of 700 million dollars over a 3 year period, of which 375 million will be spent on research and demonstration programs and the remaining 325 million will be used for other programs in the air pollution field.

I don't feel that this resolves by any means the Federal commitment. When air pollution standards are adopted and abatement programs are set up, many industries will be compelled to undertake expensive programs to install pollution abatement devices. Many proposals have been made to resolve this problem, most of them involving tax breaks for the companies involved. I will be introducing legislation next week which will set up a program of Federal grants and loans to industries to help pay the cost of air pollution abatement equipment and programs and to avoid putting unnecessary financial burdens on industries which can't offord them. The air pollution control program has been patterned to some extent after the water pollution programs. I think that we can profit by looking at the water pollution programs to give us some idea of how the new air pollution programs might work.

The Federal Water Pollution Control Act required that all the states in the United States submit to the Federal government by June 30 of this year, water quality standards for their interstate waters not intrastate but interstate waters and plans for pollution abatement of these waters. The standards are in and the bickering has begun. Iowa thinks Wisconsin's bacteria restrictions are too high. Minnesota thinks the temperature limits are too low. Michigan isn't satisfied about oxygen demand and so forth. And while all this goes on, the pollution of our waters goes on unchecked. The law, however, provides an answer for all this —the State-Federal Water Pollution Conference. Lakes Michigan and Superior are a good case in point. It is not too early to call such a Conference for these waters. The states need now more than ever before to sit down at the conference table and agree upon uniform standards for the lakes and synchronize their pollution abatement programs. If the Governor or the governors of two states join together and request a Federal State Conference, the Federal government then joins with those states and sends in engineers, the scientists and the technicians. The teams monitor all sources of water pollution in the whole watershed. They monitor it, they evaluate it, and they name the industries, the municipalities, the kind and the quality of the pollutants that each is guilty of introducing into the water. Then they sit down and work out a program for abating the pollution. And at the conclusion it is agreed that within a specified and agreed upon period say 3 years, 4 years, or 5 years pollution will be abated. If any municipality or industry declines to comply, the Federal courts are called in to force compliance.

There is no other way that I know of to stop the pollution of say Lake Michigan and to stop the beginnings of pollution and the beginnings of the destruction of one of the three greatest bodies of fresh water in all the world, Lake Superior.

As I look at Lake Superior every single summer, you can see the pollution going into it. I flew out over Superior and watched the discharges into that lake stretching for ½ mile — yellow in color from a plant in Lake Superior —it was disgusting. That lake is very delicate in the quality of its waters, similar to Lake Bical in Russia, which is the purest of all the great bodies of fresh water in the world. But Lake Superior is in terms of its quality, probably the second purest-large body in the world, it is perhaps along with Lake Tanganyika. But in delicate waters, the introduction of a small amount of pollution can have dramatic and catastrophic effects, and that pollution is now under way.

The southern tip of Lake Michigan has been badly polluted and Indiana and Illinois are in a conference about that southern tip. They will come to agreement and cease the pollution there. But the shores of Milwaukee, of Green Bay, the shores which have been so polluted for 25 years, that the beaches haven't been open for almost as many years, are not to be saved by this particular conference nor will Lake Superior. It is time that both our states — Minnesota and Wisconsin — join in a Federal Water Pollution Conference on Lake Superior and that we join with the State of Michigan on a Federal State Conference here on Lake Michigan. If we do not do this you will see the destruction of Lake Michigan in another 15 or 20 years. The destruction will be so complete that in my judgment the lake will not be usable for any recreation purpose whatsoever, and Lake Superior will follow behind it in a few years. Then you will have seen the destruction of the Great Lakes which involves 1/5 of all the fresh water on the face of the globe.

There is no question at all, but what we don't have the answer to pollution abatement for various kinds of pollutants. We do not know how to control some of the pollutants that go into the air, we don't have the sophisticated hardware and equipment which is necessary to do an excellent job. We do not know how to control at this stage in history the pollutants from the exhaust of the automobile. There are many industrial wastes for which we do not have any equipment much less the very sophisticated equipment for the neutralization or management or destruction of the industrial wastes. We have not reached the ultimate in the control of the biodegradable wastes that come from the sewage plants of the municipalities. So obviously, there needs to be a vast expansion of research in all fields of pollution. Herein lie the great challenges for our engineers and for our scientists.

We have started lots of water research on our university campuses around the country, but we need to expand that research to include profit and non-profit groups, to build more effective and sophisticated hardware because you won't resolve these problems until you have the equipment to do it. You must require that the equipment which has reached the highest status of the art be used.

So far as municipal pollution is concerned, I don't think there is any solution to it, unless we are prepared to meet the problem in exactly the same way financially that we met the problem of building the four lane, limited-access Federal interstate highway system. Congress decided it was important to this country to have such an interstate highway system. Further it was considered important enough so that Congress was willing to appropriate almost 50 billion dollars to do it. Congress also decided that the Federal government should appropriate 90% of the money to pay for the cost and that the state should come up with 10% of the money. If we had tried to solve this problem of building a limited access, four lane highway system across the nation on the same formula that we use in giving assistance to municipalities for the construction of secondary treatment plants, the highways would have never been built. We have been giving 30% of the cost, with a 2 million dollar limitation to the municipalities requiring that the municipalities come up with the other 70%. This didn't help the big cities at all —. Either the public refuses to vote the band issue or the cities are bonded to their limit already or they just don't have the capacity. We should pass legislation providing that 90% of all the cost of design and construction of an adequate size secondary treatment plant for every municipality in America, will be borne by the Federal government. You would thus effectivley meet the problem of the treatment of municipal sewage in America—a most frightful problem indeed.

The equivalent of pure untreated waste from 75 million people is going into the waters of America every single day now. And there is no result in end except the total distruction of all the water and all the watersheds in America unless it is stopped. As a matter of fact, there is not left in America a single major river basin unpolluted. Some are polluted to different degrees than others, but there is not one single one unpolluted in all of America. Industrial wastes require fast tax write-offs and loans to those who don't have the financial capacity. Again, the cost is the same. If we give loans and grants and tax write-offs it will probably cost us less than if we force compliance in the long run because there is always an additional factor added to the price of a product if you have to make an addition to plant investment. What we really want is compliance, and you and I are going to pay it anyway because if the steel companies comply and the auto companies comply and all the manufacturers of paper comply, you will pay for it in the cost of the paper, automobile, and the steel and so forth anyway, so its a consumer cost factor. Wisconsin, Minnesota and Michigan are the most bountifully blessed three states in the Nation with fresh water. Our state has 8,000 named lakes and 1,500 rivers and streams. We are bounded on the east by Lake Michigan and on the west by the third largest body of fresh water on the globe Lake Superior and on the west by the great St. Croix River and the polluted Mississippi River. The St. Croix River incidentally is the only river I can find in the whole United States which is situated near a metropolitan area. The St. Croix runs within 14 miles or so of St. Paul — which is still relatively unpolluted. The only reason that the St. Croix river can boast its relatively clean state is that Minneapolis was built on the Mississippi and the St. Croix runs into the Mississippi at Prescott — below the Twin Cities.

At the rate we are going it will only be a handful of years when there will not be left a single unpolluted lake in all of the 8,000 that we've got in Wisconsin, and we will have polluted every single one of the 1500 rivers and streams. Insofar as Wisconsin is concerned, at the rate we are now going, you can write off the entire fresh-water based recreation industry which is reaching a billion dollars a year income, and you can write off one of the most valuable of assets that this state has, the great charm of the environment in which we live.

In the State Water Resources bill that passed a year ago, Assemblyman Anderson of Madison insisted upon a proposal that he and I had been fighting for for years and that is to include the power of the state to zone the shorelines of the rivers and lakes in this state. Every lake that you and I know of which is surrounded by cottages has received its death sentence. The only question is how long will it live or how long will it take to die. In each I think it is possible to save a number of those lakes, if we have the courage to do it. It would take a bit longer to destroy those lakes with a good inlet and a good outlet but they too destroyed will be. When we allow people to buy a lot, cut the trees clear, destroying with it the stability of the shore line, we have started erosion into that lake and destroyed the scenic beauty of the land itself. The stability of the shoreline which we have disturbed had met the problem of preventing siltation for 10,000 years, that is since the glaciers.

Secondly, all of the little septic tanks are throwing pollutants into the lake and as the pollutant goes into the lake, it fertilizes it, and as it fertilizes it as you well know, you get the plankton and the algae and pretty soon the lake is destroyed. The people who invested their money and went out there to see this beautiful lake have, through their ignorance, participated in destroying this asset. What makes me feel bad is that th lake belongs to all the people in the state and not to the polluters on the shoreline.

So, unless we zone the balance of the lakes in this state and all of the rivers, and prohibit the cutting of any trees on the shorelines of the Wolf river, and the St. Croix River and the Chippewa River and the other dozens and hundreds in the state, unless we do that, we will pollute and destroy the balance of everything that we have left.

This is where the politics come in. Has the leadership at the county level and the state level got the courage to do what must be done? Well, I hope so. But if they don't, posterity will suffer as a consequence of it. The law ought to require that lakes with cottages join in a joint little sewage district guaranteeing that the effluent pipes are far enough away from the lake so that the effluent cannot get back into the lake. We have now the equipment necessary to remove 90% of the nutrients. Every cottage owner should have to join a district arrangement of that kind. Again, it is a political question of who will find the courage to enforce that kind of rule.

We have not licked the detergent problem at all despite all the propaganda of the soap people. After I introduced the detergent bill and it passed the Senate, the industry got frightened and changed the molecular composition of their products to take the foam out, but it didn't take out the nutrients, and so far as pollution is concerned, it is just as serious. I think as it was before they changed the base of the detergents a year ago last June the situation remains unchanged.

Another aspect of the problem, and there certainly are plenty more, is the question of pesticides. There are 25,000 kinds of pesticides in this country. Rachel Carson was perfectly correct in *SILENT SPRING*. Her instinct was better than the criticism made by many distinguished scientists in this country. The fact of the matter is that pesticides are doing irreparable damage to the whole ecological balance in this country. I don't think there is any doubt about it at all, and I hope in another six months or so some of my scientist engineer friends who advise me will have the proof on it. Incredible as it may seem, we have been pouring into the atmosphere in this country 700 million pounds of DDT per year for a long time. We have since found DDT in the fatty tissues of penguins in the Antarctic. The penguin does not eat any migratory ocean creatures and no DDT so far as I know has been used within 10,000 miles of the Antarctic. So, it got their via the air and via the air current and into the water and accumulated into the fatty tissue of the marine creatures consumed then by the Adelly Pequon which serve as food. A recent study found that out of a sample of 400 marine creatures 395 had DDT in their fatty tissue. We are finding it in the fatty tissue of deer and in fish. One part per several million in a body of water might not do any harm, but when it is absorbed by the plants and then eaten by the little fish, multiplication of the concentration occurs. We find an accumulation of 2600 parts per million in some fish. When these fish are finally eaten at the end of the food chain by any of the fish eating birds, the observed effect is manifested in the sterilization of the egg of the eagle or the falcon. It is a very serious, a critically serious problem, but hard to get people excited about. Well, that's a rather rapid but not rapid enough brush over of some of the problems that confront us in the environmental field. I am encouraged with the fact that in the last half dozen years, particularly in the last 4 or 5 years, there has been an awakening interest in the Congress and around the nation in these problems. I want to give great credit to both the Milwaukee Journal and the Milwaukee Sentinel and the Green Bay Press Gazette for the very dramatic and extensive stories that they have written on pollution. Ten years ago I don't think there would have been enough reader interest to justify such coverage. I don't know what comes first, the chicken or the egg, but the fact is that there is an awakening interest. I think the public is prepared to meet the cost. I think the public is aware of the fact that it will be much more expensive to postpone the solution. It might take 200 billion dollars in the next 20 years to substantially meet the problem, or it might be 300 billion dollars in the next 20 years. Yet it is certain that this is the order of magnitudes that we are talking about if the total question of restoring the quality of the air, and the quality of the water is to be resolved. To people who say that this is a lot of money, I say it is much less than will have to be paid if we don't solve the problem soon. The challenge is loud and clear. It is a challenge to the entire people and hence their elected representatives. It is a challenge to the scientists and the engineers who must work in collaboration and who must approach these broad and and inter-disciplinary problems in an inter-disciplinary fashion.

AND THEN THERE WERE NONE*

Well, she said she swam in the river,
And the water was clear below,
She said she swam in the river, Many, many, many years ago.

An the sun shone bright and golden,
And the trees were glistening green,
And the sky was blue, so blue and sweet,
and the banks were comely and neat.
How then did we come to this, Where did we lose our way,
Can it be that we shall really be, a land of tinseled grey?

Our forefathers faced a bountiful land,
From tall majestic forests to the oceans ivory sand.
Rich with rabbit, elk and deer, surging rivers fresh and clear,
Well, they plowed, and they farmed, and then moved on.

And the land baked in the sun.
No trees to shade, no roots to hold.
Bare as the days when the whole earth was cold.

Then the fur trappers roamed our great north country,
They stripped it for pelts and for skins,
And the lumbermen came, clearing pine, fir and hardwood,
To build a giant land, An impatient, needful land.

And the land baked in the Sun. No trees to shade,
nor roots to hold,
Bare as the days when the whole earth was cold.

At last the giant factories sprang up beside our streams,
Our lakes and our rivers, the echo of our dreams,
And the smoke stacks raped the air,
With their filth and their debris,
While the waters, once of crystal, Bring their
poison to the sea,
And so, we have come to this.
Dear God we've lost our way,
And it looks as tho your jewel may be a land of tinseled grey.

***Lyrics from a song based on the speech by Senator Nelson, written and sung for the Milwaukee Public Museum's TV Series "Strang But True" by Judith Ann Reisman.**