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SYSTEMS AND THINGS

Inaugural Lecture
of the Professor of Industrial Systems Engineering
delivered at the University College of Swansea
on February 13, 1973

by

PROFESSOR R. B. GRAVENOR,
M.Sc., Ph.D., A.R.I.C.

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Don't you feel a change a coming
From another side of time,
Breaking down the walls of silence
Lifting shadows from your mind.
Placing back the missing mirrors
That before you couldn't find
Filling mysteries of emptiness
That yesterday left behind.

C. Stevens[1]

SYSTEMS AND THINGS

"The idea of a 'Systems Approach' is both quite popular and quite unpopular. It's popular because it sounds good to say that the whole system is being considered, but it's quite unpopular because it sounds either like a lot of nonsense or else down right dangerous . . ."

C. West Churchman[2]

Some of you have come here this evening hoping to learn about and understand the so called 'SYSTEMS APPROACH'. Of recent times it is quite common to see articles and books with such titles as "*The Systems Approach to Geography*", "*A Systems Analysis of Political Life*" or "*A Systems Study of Hospitals*" to quote a few real examples. Almost every day on this campus I am asked "*What is Systems Engineering* ?"

I hope you will not be too disappointed for I must say right now that I am not going to explain in a direct way what the systems approach is. I will have fulfilled my personal objectives tonight if I can demonstrate to your satisfaction that some new approaches are required, in addition to the traditional ones, that this study is fittingly carried out in the Universities and that my Department has a small but finite chance of being on the right trail. Professor Checkland in his Inaugural Lecture at Lancaster[3] took a different line defining 'THE SYSTEMS APPROACH' as "*A framework which reveals the pattern of the whole of management science, and hence provides a way of structuring work within it*" and relegating other subjects such as Cybernetics, Operational Research, Econometrics, Decision Theory, Behavioural Science, Ergonomics, etc. to a subordinate level to Systems Engineering. This point of view, seems to me to lead inevitably to pointless and energy consuming debate and more importantly to partly miss the main point of the 'systems movement'—something additional and new is required, the name or

A SYSTEM IS A SET OF INTER-RELATED ELEMENTS WHICH WE WISH TO STUDY AS A WHOLE.

WE HAVE THE CAPABILITY :

OF ADEQUATELY FEEDING, SHELTERING AND CLOTHING EVERYBODY,

OF PROVIDING ADEQUATE MEDICAL CARE AND EDUCATION,

OF OUTLAWING WAR-FARE AND OF INSTITUTING SANCTIONS PREVENTING WAR,

OF CREATING A FREEDOM OF OPINION AND ACTION WITHIN SOCIETIES,

OF CREATING NEW TECHNOLOGIES TO RELEASE NEW SOURCES OF ENERGY (ETC.)

department under which an advance is made is of no consequence.

While I do not intend to directly define the Systems approach, I should say something about my approach and about the things we shall call Systems. My own approach to the problems illustrated later, is in general that of the Scientist and Technologist, for my training and experience are derived from these areas. I am therefore concerned with real and not abstract things, my approach will be nearer to Physics than Metaphysics, my approach is also, in part, experimental. I need data about systems behaviour, although the laboratory is often the real world where comparative tests and control groups are not easy to come by and the costs of experiments can be quite high. Approximations and value judgements have to be made, hence the approach is nearer to the Engineer than the Mathematician. I make no apologies for my approach. Of course I do apologise in advance to other disciplines if I malign them or if I appear to be unacquainted with breakthroughs they have already made. This could be put down to my ignorance or classified as another of those important ' Systems Problems ' that we must find answers to—cross fertilisation and good communications.

Coming then to what is a System. In terms of a formal definition a brief statement is sufficient for my purposes.

"A SYSTEM IS A SET OF INTER-RELATED ELEMENTS WHICH WE WISH TO STUDY AS A WHOLE". The word "whole" is very important and the "we" generally refers to people with a scientific background.

Systems researchers naturally study many kinds of Systems—self organising, mechanical, purposive, open, closed, dynamic, etc. but by way of further introduction let me run through a shortened version of an important system commented on by West Churchman[2] and many others.

Let us look at the inter-relation of modern technology with the problems of the world today. These problems

IT CAN BE SEEN THAT :

THE INDIVIDUAL PROBLEMS ARE INTERCONNECTED AND OVERLAPPING,

THERE ARE NO NATURAL STARTING AND FINISHING POINTS,

WE HAVE NO ADEQUATE METHODS OF ALLOCATING OUR RESOURCES BETWEEN THE PROBLEM AREAS,

SOLUTIONS TO THE VARIOUS PROBLEMS CAN BE IN DIRECT CONFLICT WITH EACH OTHER,

WE DO NOT HAVE ADEQUATE DATA TO SET STANDARDS, TARGETS AND PERFORMANCE LEVELS,

WE CANNOT EXHAUST THE LIST OF THINGS THAT WE NEED TO DO,

WE CANNOT BE SURE THAT WE HAVE IDENTIFIED THE REAL PROBLEMS.

WE HAVE ALL WE NEED. WE KNOW HOW TO DO ALL THE INDIVIDUAL THINGS NECESSARY TO REBUILD OUR ENVIRONMENT IF WE WANT TO - - -

WHAT IS NOT UNDERSTOOD IS HOW YOU FIT THE FIELDS OF KNOWLEDGE TOGETHER.

D. DUNN[4]

include such things as food, energy, medical care, education, pollution, war, freedom of the individual.

Now, as Churchman says, "*In principle modern technology can solve many of these problems today.*"

We have the capability :

of adequately feeding, sheltering and clothing everybody,

of providing adequate medical care and education,

of outlawing warfare and of instituting sanctions preventing war,

of creating a freedom of opinion and action within societies,

of creating new technologies to release new sources of energy (etc.).

This is, of course, a vast and complicated system and I must not take it too far tonight, but despite the vagaries of the statements it does illustrate some important aspects of thinking about ' Systems '.

Every one of you will realise that the problems stated are real. But we should ask—if humans have these capabilities, why don't they go ahead and implement the solutions. "*Is there some perverse streak that runs throughout the human race that makes one human being indifferent to the plight of another* ?" Some of you may say yes. But closer analysis shows that there are more subtle reasons than this.

It can be seen that :

the individual problems are inter-connected and overlapping,

there are no natural starting and finishing points,

we have no adequate methods of allocating our resources between the problem areas,

solutions to the various problems can be in direct conflict with each other,

we do not have adequate data to set standards, targets and performance levels,

we cannot exhaust the list of things that we need to do,

we cannot be sure that we have identified the real problems.

We can, in fact, sum up our conclusions above in the statement that WE HAVE A VERY LIMITED ABILITY TO THINK ABOUT AND TACKLE LARGE SYSTEMS PROBLEMS. One has only to look at the real problems surrounding us today to convince oneself of the accuracy of this statement.

Even in California they have their problems :

We have all we need. We know how to do all the individual things necessary to rebuild our environment if we want to . . . What is not understood is how you fit the fields of knowledge together.

D. Dunn[4]

Other examples of Systems that readily come to mind are :

Transportation Systems—land, sea and air.
Communications Systems.
A City or New Town.
The Respiratory System.
Computer Process Control Systems.
The Tax System.
Public Utilities.
Large Corporate Bodies and Companies.

Leaving these examples and without explaining formally any more of the Systems Approach, I want now to show that the classical approaches to such problems suffer from severe constraints. Hence justifying research into new concepts and methodologies.

Some 25 years ago the celebrated mathematician Norbert Wiener ended his famous book "Cybernetics"[5] thus :

"*There is much which we must leave, whether we like it or not, to the un'scientific' narrative method of the professional historian.*"

This book was the first major work of a Systems man. Today, however, many scientists and engineers are saying aloud : MAYBE, BUT NOT HALF AS MUCH AS HE THOUGHT. Wiener was subconsciously constrained in his thinking by acceptance of the limitations of conventional mathematical, scientific and philosophical approaches which are no longer acceptable today even though the information upon which we make this decision was available to him. It is one of the purposes of my lecture tonight to demonstrate that these limitations cannot and must not be accepted if we are to make significant inroads into the study of the behaviour of important systems.

Let us now look at some of the limitations on conventional methods that we will have to remove in developing a new approach. My selection is not exhaustive and we must constantly be on the look out for less obvious barriers to our thinking process.

It is natural for me to start by considering the conventional scientific method. A useful way of looking at this process was recently communicated to me.[6] The scientific method can be likened to the process of long divison :

$$\begin{array}{r|l} & \gamma \cdot\ \gamma_1\ \gamma_2 \\ \hline \alpha\ ) & \beta \\ \hline & \quad R \end{array}$$

The current thoughts α are applied to a field of study β until there is no remainder or until the remainder is negligibly small. But these remainders have a nasty habit of being very stubborn and not being easily removed. The 19th Century Physicists found this with black-body radiation anomalies and the negative results of the Michelson-Morly experiment. One then needs a revolution in the methods and ideas before significant progress can be made. To the end of his days Einstein was unhappy about his inability to unify the two breakthroughs in Physics, Relativity and Quantum Mechanics, that when applied separately, but not together, to certain fields removed the remainder. The obvious extension of this analogy to different types of numbers and higher arithmetic could prove a fruitful process.

THE 28 GeV ACCELERATOR AT GENEVA SUPPORTS AT LEAST 1000 STAFF

300 GeV ACCELERATORS ARE BEING BUILT AT GENEVA AND BROOKHAVEN

THE ACCELERATOR AT GENEVA WILL TAKE 5 YEARS TO BUILD AT A CAPITAL COST OF £100 MILLION *and I would estimate an equal amount in annual operating costs.*

IT TOOK 2 YEARS FOR THE SOPHISTICATED EXPERIMENT TO BE SET UP BOTH AT CERN AND AT BROOKHAVEN AT ABOUT THE SAME TIME. IN 1964 THE PARTICLE WAS SEEN IN A BROOKHAVEN BUBBLE CHAMBER EXACTLY AS PREDICTED.

THAT THE PURSUIT OF HIGH ENERGY PHYSICS AS A BRANCH OF LEARNING MAY WELL END SIMPLY BECAUSE THE EXPERIMENTS HAVE BECOME SO BIG AND COMPLEX THAT THE SPIRIT OF THE PHYSICISTS WILL NOT BE SUFFICIENTLY STRONG TO CONTEMPLATE THEM.

Today, as I see it, the main problems with this method are it takes too much time, it is proving very costly in terms of money, human energy and human resources, it is causing ever-increasing divisions and specialisations in Science and Scientists are in danger of not realising that they are constrained in their thinking by their own methods ; we no longer see the woods for the trees.

Again we turn to Physics, the most mature and respected of the Natural Sciences to find outstanding examples of these trends in action.

In a recent Government publication, "Growing Points in Science"[7], Dr. A. Merrison, Vice-Chancellor of the University of Bristol, in an article on elementary particles, gave the following pieces of information :

"*The 28 GeV accelerator at Geneva supports at least 1000 staff.*"

"*300 GeV accelerators are being built at Geneva and Brookhaven.*"

"*The accelerator at Geneva will take 5 years to build at a capital cost of £100 million*" AND I WOULD ESTIMATE AN EQUAL AMOUNT IN ANNUAL OPERATING COSTS.

"*It took 2 years for the sophisticated experiment to be set up both at CERN and at Brookhaven at about the same time. In 1964 the particle was seen in a Brookhaven bubble chamber exactly as predicted.*"

One cannot but gasp at the magnitude of such research projects and wonder whether these projects represent a distortion in the allocation of the vital resources of first class, highly trained physicists and money.

Dr. Merrison also quotes Professor T. D. Lee as suggesting "*that the pursuit of high energy Physics as a branch of learning may well end simply because the experiments have become so big and complex that the spirit of the Physicists will not be sufficiently strong to contemplate them.*"

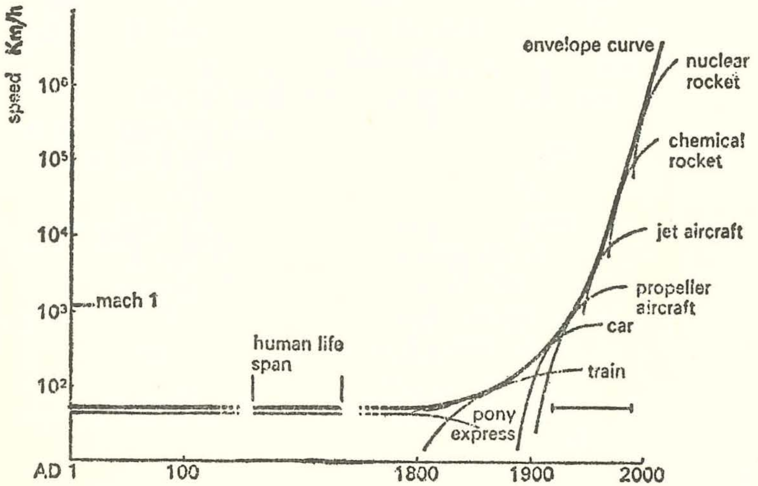
Personally, for the sake of high energy Physics, I hope that their spirits will be strong enough to rebel before this stage is reached !

A COMPUTER THE SIZE OF THE EARTH AND WORKING FOR A TIME EQUAL TO THE AGE OF THE EARTH COULD NOT PROCESS MORE THAN 10^{92} BITS. NOW MANY EVERYDAY SYSTEMS PROBLEMS REPRESENTED IN CLASSICAL FASHION CAN BE SHOWN TO GENERATE MANY MORE BITS OF DATA THAN THIS.

THE NUMBER OF POSSIBLE MOVE SEQUENCES IN CHESS—10^{120} BITS.

PROBLEMS OF SIMPLE CELL EVOLUTION BASED ON RANDOM CHANCE INVOLVE 10^{3000} BITS.

NETWORK COMMUNICATIONS PROBLEMS INSIDE A FIRM OF 300 PEOPLE COULD INVOLVE 3 x 10^{92} BITS.



The divisiveness and the large scale of resources that are now being spent on the pursuit of the scientific method naturally leads us on the next major constraint, how do we cope with the information explosion[8] and in general with the exponential growth rate of nearly all of man's external capabilities such as speed of travel, use of natural resources, population growth, size of communications systems, etc.[9] Not only are we faced with a high growth that threatens our ability to keep up with the game without becoming more and more specialised but in this present era we are faced with a step function change with respect to the amount of change that anyone in his lifetime can expect. Until now, an order of magnitude change in man's capabilities has taken many lifetimes to appear, now we get many orders of magnitude change during a single lifetime.[10] You have only to compare your travel habits with those of your parents or compare your kitchen with theirs and the ones in the showrooms, to see these changes. Where do we look for a solution to these problems. It is not within traditional fields of study.

The computer has often been put forward as a saviour in the fields of exploding amounts of information and numbers of equations but Bremermann[11] conjectured that a computer the size of the earth and working for a time equal to the age of the earth could not process more than 10^{92} bits. Now many everyday Systems problems represented in classical fashion can be shown to generate many more bits of data than this.

The number of possible move sequences in chess ~ 10^{120} bits.

Problems of simple cell evolution based on random change involve 10^{3000} bits.

Network communications problems inside a firm of 300 people could involve 3 x 10^{92} bits.

Without organisation and planning and new methods, the computer will not help us in some of these systems problems.

One could go on with these examples, to show how we have distorted natural physical laws, that we do not fully understand, e.g. hardness[12] so that we can use the rules of arithmetic to deal with them—what else is the so-called cost—benefit or cost—effectiveness analysis in Management Science. We could expose the limitations of current mathematics techniques in dealing with discontinuities.[13] We must also expose some of the teaching and philosophical constraints imposed on us. I agree with another Systems Researcher[14] who said that Wittgenstein and Russel were wrong and misleading in such statements as :

The world is everything that is the case
The world is the totality of facts, not things.
The facts in logical space are the world.
The world divides into facts.
Anyone can either be the case or not be the case,
and everything else remains the same.

L. Wittgenstein[15]

The essential business of language is to assert or deny facts.

B. Russel[15]

SYSTEMS RESEARCH IS NOT ABOUT PROBLEMS BEING BLACK OR WHITE. IT IS ABOUT LOOKING AT GREY AREAS AS GREY AREAS.

In our Department we know about these and other constraints and limitations because when we try to look at Systems such as the interactions of computers with society or allocation of resources in a design office or R. & D. laboratory, or non-linear and discontinuous process and production control systems, we come right up against them !

While the limitations that I have mentioned at first sight seem fierce and forbidding, these are not reasons for giving up the problem of breaking them and pursuing more conventional routes. For a long time now the

Physicists and Mathematicians have learned to live with and not be contained by problems of infinity and physical uncertainty. What could appear more daunting than the idea "*a part can be equal to the whole—a characteristic property of infinite sets*"[16] when "*part*" and "*whole*" have their conventional meaning or the fact that you cannot measure simultaneously the position and velocity of an electron. Again, one has to struggle in the problems of cosmology with the concepts of instantaneous or continuous creation.

What is important to progress is that the limitations are recognised, to know when it is safe to work within them and to try to find more powerful concepts that will break these barriers when they become constraining.

Over the last 25 years or so researchers have been turning their attention to Systems as wholes. Of course Biologists have been working in this field, often literally, for many more years than this and others would claim that the roots of Management Science also go back further. The roots of the family tree, although interesting, cannot be traced tonight but the resultant fast, recent growth in the study of Systems has come at about the right time (not too late), for all over the world people are now face to face with systems type problems.

What must be controlled from now on, however, are the twin dangers of an emerging discipline. The first being that it is oversold as a cure for all our problems, this leads to over-confidence and insignificant work by the researchers and to disillusion on the part of the customers. The second lesser danger is divisiveness, with the practitioners of each separate discipline causing wasteful internal conflict and communications difficulties and each of them separately falling into the overselling trap. There is an invidious trap in even having a "Systems Department" or "Business Administration Department" when, perhaps more than any other subject at the moment, cross fertilisation is required. The study of Systems needs political, economic, sociological, philosophical, cultural, engineering and science inputs. We need to avoid possible departmental constraints. At Swansea I intend to do all in my power to avoid them.

Coming back then to the first danger. In this talk I have deliberately kept the Systems concept broad and diffuse. For that is the state of the art today. To speak of the Systems Approach as a well organised and defined discipline is untimely at best and grossly misleading at worst. We can recognise systems problems but as yet we have very few laws of the behaviour of Systems. One can think some such as '*requisite variety*' '*homeostatis*' and '*entropy*', very powerful general concepts, but very few others. Some conjectures are made later. Within the conventional framework there is a general body of knowledge and theory emerging in subjects such as Management Science, Behavioural Science, Control Engineering, Policy Research, Futures Studied and Ecology in its broad sense. In our Department and many others, contributions are being made to this level.

If we do not have a well defined subject, then what do we have now ; in the main there is a considerable and ever growing body of talented people who are working away in various places on a variety of topics, who are running up against constraints such as I mentioned earlier and who are determined to break out from them. This is an internal driving force satisfying personal needs.

There is also a growing awareness by and pressure from society that large Systems must be studied by better methods than we have had in the past. People are no longer prepared to accept third airports or docks closures, or bankrupt international companies without real justification. This seems to be part of man's natural development. This decade has also seen a new and dramatic movement appearing. With the landing of Armstrong and Aldrin on the moon people have realised that if we know or can truly work out what we want to do then we can do it. This normative attitude will be a routine way of thinking in the so called '*post-industrial state*'. These

are external driving forces brought about by the practical needs of survival, advancement and growth of society at large.

Having talked about why we need new methods of looking at Systems and having said that we don't have much of use yet I feel a certain amount of freedom to conjecture about the likely shape of things to come.

We will learn to study Systems as wholes, this will be done by experiment and experience as before but simulation will play an ever increasing part in the experimentation. The biggest steps forward will be made by studying more complex systems and simplifying rather than by studying smaller Systems and attempting to relate the parts.

General laws pertaining to the behaviour of Systems will emerge. One sees the signs already in such concepts as 'synergy'—the whole being greater than the sum of the parts, in generalisations of ideas derived from Physical Sciences, the uncertainty principle—you cannot observe a System without changing it, the ideas of entropy and disorder. Such concepts will help us limit systems and define their boundaries.

We will learn newer, higher level, languages to talk meaningfully about the objectives and goals of Systems. We will have to drop notions of optimisation and maximisation when dealing with large Systems. Conflict and catastrophy as we think of them today will always be present in the lower level languages. We will not be so cynical of present day adhoc, compromise, political, mutually agreed, practical solutions when we debate them in higher languages. Reflection on, or really trying to give answers to certain topical questions make us realise that they are non-questions, they have no meaning ! For example (IS AN R. & D. DEPARTMENT [OR A UNIVERSITY] SHOWING A PROFIT) is such a non-question. We will learn to ask much more significant questions and to deal with much more complex answers, all in an atmosphere of understanding.

LET US LEARN TO DREAM, GENTLEMEN, THEN PERHAPS WE SHALL FIND THE TRUTH.

AUGUST KEKULÊ[18]

IT WAS SO PRETTY IT HAD TO EXIST.

J. D. WATSON[17]

THERE IS A UNITY ABOUT THE FABRIC OF SCIENCE HELD TOGETHER BY THE EXCHANGE OF CONCEPTS AND TECHNOLOGIES. IT IS A UNITY THAT TRANSCENDS THE DISCIPLINARY INTERESTS - - - -

SIR B. FLOWERS[21]

The new discipline will demand much more involvement of the person, much less reliance on "cold scientific detachment" and more reliance 'on a sixth sense' in looking for solutions, when already soaked in the data required for the solution. These same signs are also showing through as being important in scientific research. Evidence can be seen in Watson's "The Double Helix"[17] in Kekulé's dream of the Snakes[18] and in Medawar's little book "Experiment"[19]

'Let us learn to dream, gentlemen, then perhaps we shall find the truth'.

August Kekulé.[18]

The experience of many fields outside Science will often be invoked in the solution of Systems problems.

"It was so pretty it had to exist"

J. D. Watson[17]

During the next few years the Systems field will benefit considerably from other major disciplines. There are already indications of major inputs into Systems from such fields as the study of human autonomic systems where recently it has been demonstrated that by simple feedback techniques these Systems can be brought under conscious control, from Pure Mathematics where studies in Geometry will have significant application in thinking about step function changes[20] and from the so called 'new Mathematics' that will help us talk about Systems in 'exact quantitative terms'. Many people have predicted that the next decade will be the era of the biologist. I hope so, because as the oldest of the Systems thinkers they can then contribute much to the thinking of the "new boys". After that, I have great hopes of the Sociologists.

Individual parts of the Systems field such as Cybernetics, Information Theory, Control Engineering, Policy Research, Autonomics and Computing will also produce reliable techniques and methodologies to add to the Systems range.

Within the next decade I expect to see Systems studies take a normal place alongside all the other more traditional activities of a University. Then I will be able to deliver a much more specific lecture on what Systems are all about.

These things are then happening or are going to come about and when one takes account of the needs that are being satisfied it comes as no surprise that the major contributions in this field are being made in sophisticated industrial concerns and the Universities.

Advanced industrial companies have long since realised that they have Systems problems to solve. Problems of production and process control, of the best use of advanced technology, including computers, problems to do with their size and interaction with the rest of society, problems of being multi-national. Advanced industry is the laboratory where many systems problems can and are being studied. This is a very good reason for a strong link between the Universities and industry. On the whole, I have found people in industry more aware of Systems problems than most other people. It should also be made clear that the armed forces and industry really gave birth to Systems Thinking and in its earliest days provided the strongest possible support to people working in this difficult area. Most Universities' Operational Research dept., Control Engineering dept., etc. have a high percentage of their staff who started to formulate their ideas in industry. Much will be lost to the subject if this link is broken.

After the nuturing of these first Systems studies in the forces and industries like the N.C.B., and B.S.C., the activity slowly spread to the Universities, at first the newer Universities like Lancaster, Sussex and later to the red brick Universities and even to Oxbridge and now to the Open University. As usual, the movement came under various names, departments of Operational Research, Management Science, Cybernetics, Control Engineering, Systems Engineering and Business Schools.

When one looks at this general movement towards the setting up of more and more Systems and related departments and courses in higher education, one may conclude that ' by definition ' Systems is an acceptable subject to be studied at the Universities. But since this could be just another fad or fashion I would like to look a little bit more deeply into why the University is a most suitable place. Lord Annan in the first Dimbleby Lecture[22] studied the problem ' *What are Universities for, anyway* ? ' He developed his theme along the lines of : ' high level students being taught in an atmosphere of research and scholarships, of new knowledge being discovered and created, of the transmitting to each generation of high culture, all, in one of the last refuges for the contemplative life '. It is obvious that these points can be used in an argument to support a Systems activity in the University. That new knowledge in this field needs to be created and discovered, taught and transmitted and that the subject is concerned with high culture and requires much contemplation and inward searching has, I hope, been demonstrated in the earlier parts of this lecture. After thinking along these lines for some time, specific examples become clear. They add weight to the argument and cover points made by critics of the present University system.

Many of the problems students are deeply concerned about today are of a Systems Nature, the reasons for their attack on many of today's institutions can be found in our inability to tackle systems problems, the rise in interest of mysticism and oriental religions could be related with the limitations of Western Systems Thinking.

Systems research in comparative terms is young, it is interdisciplinary and needs much advanced level cross fertilisation, it needs much research, it needs the contemplative atmosphere to nuture and protect it in these still early days as well as to enhance it.

Many Systems problems are industry type problems also, yet being a young discipline, it needs a special Industry/University relationship. There has to be time to think about these problems over long periods ; this is often just not available even to willing industrial managers, because of the day-to-day pressures of their normal routine. I was interested to see a 'T.H.E.S.' article[23] the other day which suggested that the biggest pay-off from University research in industry came from the provision of a pool of talent and knowledge and not from specific product or process ideas. Many technologically sophisticated companies that I know would strongly support this thesis.

Systems problems are about change and about changes that we want and need to bring about. The University is about excellence. Society today needs to be excellent at solving the problems of change.

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