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YANG JIACHI

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FOREWORD

Over the long history of mankind, the productive power of man has always been in the process of development. This process consists of periods of gradual evolution with certain waves of rapid revolutionary events which were usually initiated by a number of scientific discoveries and technical inventions. The first industrial revolution was probably the single, most momentous event in our history. It was produced by mankind's mastery over mechanical power as a replacement for human and animal muscle power. Now we are in the midst of a new technological revolution. Many disciplines of science and technology are affecting the course of this revolution. However, the explosive development of informatics, including communication, computers and control, exerts the most immediate and extensive influence on the course of this revolution. For today, the main limitation to the advance of technology is the very complexity of the machines and systems we have created. Control is the limiting factor, and modern informatics is the direct result of our need to control the complexity of the devices and systems that we have so ingeniously created.

Systems scientists of many countries have studied the dynamics of the development of technology over the centuries and found that the time period between technological innovations and practical applications in production has been shortened and that the world is more and more becoming a very complex system where technology and socio-economic factors are all interrelated state variables. Without control, this new technological revolution will inevitably follow along lines similar to the first industrial revolution and the result will be an unbalanced world with enormous economic power concentrating with a few nations. This development will not leave some developed countries with traditional industries uneffected, yet it is already a great challenge to the developing countries, especially those still not industrialized.

More than a hundred years ago, Karl Marx predicted that science will also be a productive power. In order to meet the challenge of the world-wide technological revolution, science and technology should be looked upon as a useful tool, vital to the economic development of developing countries. In the meantime, academic work in science and technology must closely integrate with the needs of production. The achievements of control science and technology will certainly give an opportunity to the developing countries if they are effectively applied to saving water, energy and natural resources and to the improvement of management. By using appropriate technology including proper level of automation, the technical gap between advanced and backward facfories can be narrowed, the quality of products improved, and the efficiency of the operation raised.

Scientists from several international professional societies and organizations of the United Nations have long concerned with the status quo of the world technical revolution and its effect on the future of mankind. Many conferences have been organized to discuss new trends of the technical revolution in general. The aim of this Conference is to provide an international forum for the presentation of the latest research results and experiences dealing with a broad scope of control science and technology for development.

According to the aims and scope of the Developing Countries Committee of IFAC, "DECOM is concerned with identifying and promoting the fulfilment of the diverse needs of countries seeking increased industrialization. ...... In the context of this Committee, the term industrialization is intended to pertain primarily to the application of control systems and automation to production processes, agriculture, housing, transportation, trade as well as health and education services."

We hope that this Conference will be able to fulfil the aims our committee members are dedicated to and also the intentions of our International Program Committee.

CONTENTS

SYSTEMS SCIENCE AND CHINA'S ECONOMIC REFORMS

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Widespread and far-reaching economic reforms are sweeping China in a planned manner. The courage and pragmatic spirit demonstrated by the Chinese government in these reforms has not only won enthusiastic support from the Chinese people but also attracted much attention of both statesmen and economists throughout the world. The opening of the fourspecial economic zones,Hainan Island, and 14 coastal cities to foreign investment, the smooth settlement of the Hongkong issue by means of "one country, two systems" have undoubtedly added new meaning and implications to China's economic reforms, thus giving them an even greater momentum. Some press people even contend that China's strategy of "one county, two systems" is the most daring and fascinating initiative ever attempted in the 20th century.

China is a big country and once had a glorious ancient civilization. But ever since the industrial revolution, it has been lagging behind. The history of economic development throughout the world with different civilizations has provided valuable experience for China's reforms. Summing up its own experience of the last 35 years with successes and failures, China has adopted a new economic policy. This new policy, in my view,has been formulated by absorbing the most splendid essentials of various civilizations of mankind and discarding what has been proven by practice to be useless. The life-and-death competition on the free market in the ear Adam Smith(1723-1790), the theory of Parson Malthus(1776-1834) on ruthless war and pestilence, the Utopian Socialism,the theory of moderate government intervention advocated by John Maynard Keynes(1883-1946), and the postwar resurgence of Japan have all served as philosophical references for China's economic reforms. However, the direct reason behind the current reforms has in fact been China's own bitter experience over the past thirty years with the straits caused by the rigid structure of centrally running the entire national economy. Yet according to the title of this paper, I am not going to discuss in detail those political, economic, and ethical motivations and implications associated with China's economic reforms, but only to brief on the important role that the modern systems science has played and is potentially capable of playing in the current reform of China.

Several decades ago, people referred to political economy as a dismal science. Economists eventually recognized that by the only means of emotional and conceptual descriptions it was difficult to reveal a nation's economic state and particularly the dynamics of economic progresses. It was even harder to provide means for unbiased evaluation of given economic policies and, moreover, to predict the outcome of such policies. Thus econometrics emerged as the times required. Not surprisingly, one could say that economitrics has saved the old economics from its impending misery. Because of the advancement made in statistics and particularly with the commercialization of computer technology, the application of systems science and system control theory to the study of economic problems, military affairs, managerial science, population issues as well as sociology has become a powerful trend of our times.

This trend has been further accelerated by the emergence of the general systems theory, the founder of which is widely believed to be Von Bertalanffi who started his carrer as a researcher in the feild of biology (Theoretische Biologie, 1932). Towards the end of 1960s, Professor Ilya Prigogine (1917-) who worked for years as the director of the center for Statistical Mechanics and Thermodynamics at University of Texas, US, developed a theory on disspasive structure which greatly promoted the development of systems science, for which he received 1977 Nobel Prize. The rapid development of system control theory and computer technology over the past twenty years has provided new and powerful theoretical methods and tools for the study of econometrics and other social phenomena.

Beginning in 1977, after ten years of internal upheaval, natural and social scientists in China quickly caught up with the pace of the world scientific advancement and started using systems science and control theory to study Chinese economics, demography, and other most pressing issues, and have obtained heartening results in every aspect. It can be said without exageration that current economic reforms in China have benefitted considerably from the application of systems science. Chronologically, the earlier achievements were made in the field of population system control which was subsequently realized in China's family planning program. Then a series of excellent investigations were conducted in relation of economic issues, especially in the study of energy and pricing systems. Recently, the method of system analysis is beginning to be used in the country's macroeconomic planning. In all these areas, the State Council can timely solicit opinions from scientists. At the same time, a large amount of data from system analysis are available for policy-making at the State Council on a fairly reliable scientific basis.

Having faced the entire history of mankind in the past, China today is fortunate enough to be able to draw on experience and lessons from the evolution of civilization in various countries and, in particular, from the achievements of modern science.

I. POPULATION SYSTEM CONTROL

Population size and its growth rates can greatly affect the develoment of a country's economy. For example, the amount of discovered main kinds of China's maieral reserves ranks third in the world, however, it recedes into eightieth if its per-capita share is considered. Having faced the huge size and high growth rate of population, since seventies the government of China has given a top priority to the study of population problem, analysis of its present state and trends of growth in the future.

As far back as 200 years ago, when Thomas Robert Malthus wrote his essay on population, the population size of China had already reached 200 million. 150 years after, according to China's first census in 1954, it went up to about 600 million. Beginning to feel the pressur from its population, the government of China realized that there was a need for controlling the rate of population growth. In 1957, Mao ze-dong said ironically:" In terms of child births, human beings seem to be least capable of controlling themselves and there dose exist a situation of anarchism. If this situatino was allowed to proceed unchecked,China's population would experience a ten-fold increase to reach 6 billion and mankind would take the road of early destruction and doom". Despite what he said, at that time the government did not take much effective measures to check the pace at which the population was growing. In 1964, seven years after Mao's remarks, the second census showed an increase of another 100 million, making a total of 700 million. Soon the "Cutural Revolution" came. By 1969, even before people could extricate themselves from chaos and agony, an increase of another 100 million people was recorded. By 1974, the total reached 900 million. During that time, people lived in confinement, yet they were completely free to indullge themselves in reproduction capability. Between 1964 and 1978, China recorded a population growth of 250 million, more than the population of US was added within 13 years, but hardly any growth in GNP.

After more than ten years isolation from the outside world, during a visit to Europe in 1978, I happened to learn about the application of system analysis theory by European scientists to the study of population problems with a great success. For instance, In a "Blueprint for Survival" published in 1972, British scientists contended that Britain's population of 56 million had greatly exceeded the sustaining capacity of ecosystem of the Kingdom. They argued Britain'S population should be gradually reduced to 30 million, namly, a reduction by nearly 50 percent; some Dutch scientists also believed that Netherlands' population of 13.5 million had far gone beyond the limit of what the country's 40,000-square-kilometre territory could possibly bear and should therefore be reduced at least by a half. I was extremely excited about these documents and determined to try the method of demography.

In China, the controvercy over the population issue has beengoing on for well over 100 years. Scholars, basing their arguments on their own philosophies and theories, have often come up with completely opposite views. Some statement once held that the ultimate weapon for China to resis foreign invasion was to maintain a large population. consequently, any theory that stood for controlling the rate of population growth was regarded as the reprint of Malthus and was therefore condemned. Nevertheless, those who advocated population control resisted furiously, what frequently led to firestorm of political conflicts. Up until late 1960s, the efforts to find a solution of this age-old proposition whether or a smaller population was good for China was still permeated with danger. History already made it clear that the often mis-used literal exposition alone was incapable of resolving the pending confussions, and only the language of nature science would be powerful enough to clarify the concept and problem-setting in China's population study excluding sentimental biases of the public. This time we decided to go another way, differdnt from that of the old generation of Chinese demographers who had been rounly abused in 1950s. In fact,data,equations, theorems and corresponding conclusions, especially the irrefutable mathematical logicare far vulnerable to criticism. Moteover, one could withdraw himself into the sanctuary with high prestige of natural science if necessary. Today we are gratified to note that all of these objec-tives have been attained. We indded have been enjoying the blessings of system science and mathematics.

More precisely, in the research on population systems, we have done the following; 1-3

1) We have elaborated two kinds of mathematical models of population evolution in accordance with the actual conditious in China. One is a system described by partial differential equation with closed feedback at the boundary. The other one is expressed by a system of differencial equa-tions. The two models are equivalent in terms of physics, but each has its own advantages. The first is convenient for theoretical analyses while the latter is suited to caculation. The verification of the models by the historical data of cencus and survey statitics has shown that their logical structure and accuracy are quite satisfactory.

2) In 1979, for the first time in China, we accomplished long-term projections of the trend of China's population growth. Being published in 1980, it shocked the people throughout the country and also caught the attention of the government. The six curves of projections made it amply clear to the people that if the average fertility rate was maintained above the level of 3.0 of 1970s over a long period of time, China's population by the second half of the next century would go up to 4.5 billion equaling the total world population today, and it would continue to grow forever. If the people and government want to see China's population stabilized on a stationary level, the average number of child-bearing per woman must not exceed 2.0; if people would like to have China's population reduced below 700 million, which is admited the preferable size for China, during the next two decades each married couple should be encouraged to have only one child. Even then, it would take 70 years to achieve this goal. The predicted trends of population growth according to different total fertility rates β for a century period are shown in fig. 1.

3) We formulated the Lyapunov Stability Theory for Population Systems, and succeeded in proving a central theorem of instability. It is proved, that for any community there exists a critical total fertility rate β_{cr} , which is uniquely determined by age distribution, mortility rates and fertility pattern of the female population. The population system is stable in the sense of Lyapunov if and only if the actual total fertility rate β is not greater than β_{cr} . In other word, if the total fertility rate is permanently greater than its critical value,

the population system is unstable, and any small positive perturbation would result in an unlimited increase in population size as time tends to infinity. In late 1970s and early 1980s, the value of critical fertility rate of China's population was estimated as 2.2. But 1982's census show was 2.45. Despite the spectacular success China's family planning program has already achieved, continuous effort must be made to reduce the total fertility rate below the level of 2.2, so as to ensure the stability of China's population system. Theoretically, this stability theorem is applicable to any country or nationality, it might be particularly useful for analysis of population in developing countries. The reason for rapid growth of the world population rests with the developing countries whose total fertility rate is three to four times greater than their critical fertility rates. It is surprising that today there are still some scholars who kick up a row against family-planning program instead of worrying about the fate of billions of our future descendants. This demonstrates how weak the voice of systems science is, for there are still quite many intellectuals who, starting off with biassed sentiment, go so far as to challenge the irrefutable logic of natural sciences.

4) In the aspect of mathematical study, we have thoroughly investigated the properties of so called population operators. We accomplished the study of the asymptotic behavior, spectral properties, contrallability, completeness of eigensolutions, and so forth of the population operator. In addition to its possible theoretical significance, the results of the study has also enhanced our sense of confidence and security.

5) Following the policy relaxation for China's rural areas, the peasants have been prospering day by day. Many of them now ask the government to permit them to have more children. Why not let each married couple have two children, one boy and one girl to make an ideal pairing? But our policy-making support software promptly reports that, if each married couple of the peasants, who represent 80 percent of the total population, was allowed to have more than two children, China would have to be prepared for accomodating two billion inhabitants by the end of the next century, doubling the current population size. To other questions related to the two billion, economists have been called upon to find answers. But unfortunately, not a single economist has ventured to satisfy the request of the peasants.

Theories have revealed to the people a conclusion that some years later the ideal arrangement will be two children per couple, one boy and one girl. But not today. At least before the end of this century, we must stick to the policy of one child per couple, so that the people of the 21th century will be able to enjoy family happiness. This is an expedient measure intended as a compensation for the erroneous policies of the past that fostered uncontrolled population growth in the three decades. It is a price our children must pay for the mistakes made by their grandparents.

II. A RATIONAL PRICE SYSTEM
—— KEY FOR TRANSITION TO NEW SYSTEM

In October 1984, the government of China openly confessed that a rigid economic system has taken shape in China over the last 30 years due to both historical and political reasons. The main maladies inherent in such a system are: the government places excessive and extremely rigid control over the enterprises; the role of market mechanism is neglected; equalitarianism has prevailed over a long period of time in the distribution of social wealth, under which enterprises live off the "big pot" of the state whereas workers live off the "big pot" of firms. Such practices have severely stufled the enthusiasm and creativeness of the worker and inactivated the enterprises.

Roughly speaking, the current economic reform is mainly aimed at considerably developing commodity production and widening market activities so as to enable the market to play a more active role in advancing and regulating economic growth. The government of China realized that a fully developed commodity economy is an inescapable stage in attaining a modern social economy, and the centrally planned sector of the national economy must be narrowed by a wide margin. For a country as big as China, it is absolutely inconceivable to place the development of its national economy solely on the basis of centrally planned production and consumption. Therefore ought to be encouraged to complete with one another in the marketplace, thus permitting some firms and individuals to get better off earlier.

A distribution system based on absolute equalitarianism can only lead to common poverty instead of common prosperity. We must also draw on and absorb all advanced managerial experiences and practices of various countries in the world, including the highly developed capitalist countries. Finally, the most important prerequisite of the present economic reform is to relax the government control over pricing system, and enlarge the circulation spheres of commodities with prices left to respond to supply and demand situation of the market. In short, the ultimate goal of China's economic reform is to build an economic system full of vigor and vitality inspired by market activities and, at the same time, controlled by the government macro-planning. Thus, such system should be driven by a mixed mechanism of market flexibility with moderately centralized control.

Obviously, the economic reform must begin with changing the pricing system, gradually releasing the prices of commodities to be floated instead of the rigid practice of government hold throughout the country. The fate of the intended economic reform will be entirely dependent upon the success of pricing system reform. It is said that economic reforms are different and cold and they sometimes appear to be full of charm, glamor, and fascination. Whereas on other occasions they might be accompanied by danger and disaster. For if the social wealth failed to increase rapidly, the relaxation of price control and the spontaneous wage increases would give rise to unchecked inflation, that could adversely affect the living standards of hundreds of millions of people. As an agraring country, Chinese people have been hitherto enjoying the stable and low-priced agroproducts due to a huge sum of financial subsidies provided by the government. The first problem facing the present economic reform is to design a strategy for relaxing the government price control over agroproducts.

Two years age, as intrusted by the government, we organized a team of system analysists to study the above mentioned problem. Our efforts resulted in the establishement of a model for the pricing dynamics of agricultural and related products, which covers 237 items of 45 categories and is consisted of 114 equations, among them 19 equations in time series of dynamics, 43 for state description, and 52 for equlibrium. There are defined 142 structural parameters, including 43 endogennous and 20 exogenous variables and three types of policy control variables: purchasing and retailing prices, rate of wage increases, and taxation. The interdependent relationships among different variables constitute a large-scale dynamic system. Having reached the level of stable operation, the system now is permanently resident in a large computor data base and ready for running at any time. A careful verification of the model with over 3000 items of statistical data from the last couple of years has shown an error less than 5 per cent for short-term projection. It has provided a convenient tool for pricing system. Taking into account the supply-demand balance, price index, increase of government revenue, cash flow, etc. as the most important parameters for policy evaluation, we studied many possible ways for transition from the existing pricing system to a new one, and submitted official report with a number of choices for government to make its decision. Some general remarks and conclusions contained in this report may be briefed as follows.

1) The average annual government subsidies have amounted to ¥20 billion in the past several years to hold down the prices of agricultural products. The 1983 figure of governmental compensation is well over 30 billion, about a quarter of the total government financial revenue. If the pricing system was to remain unchanged, the subsidies would probably grow at a rate of ¥10 billion each year. Then after three to five years, annual expenditure of government in the form of subsidies for price stabilization of only agricultural products would consititute about one third of the total government revenues, thus it would become unbearable burden on the government and then even harder to carry out the transition to the market-floating price system.

2) Over the last five years, China has experienced an average annual GNP growth of 9 per cent and a national income increase of 8 percent. In 1984, a 13 percent growth in GNP and 12 percent increase in national income were recorded. A careful study of the price system dynamics described by abovementioned model has shown that the favourable economic growth rates in recent years laid a sound foundation for the government to initiate the process of reform, reducing gradually subsidies for agricultural products and releasing their prices to be regulated by

market mechanism. Some practical schemes have been devised to complete the reform within three years. The related projections indicate, the increase of wages would cover the ascent of price-index and people's real income would not decrease nor would inflation occur.

3) The release of the centralized pricing system for agricultural product should be started up at the earliest possible time. If this could be done right now, the government revenues would go up considerably in the years to come.

4) The short-term predictions made with emphases on different economic targets provide a number of choices to the government to make its decision. One of conclusions has shown that, with a 18 percent increase in retailing prices, about 20 billion RMB would have sufficed to add to the total amount of wages for keeping the balance between demand and supply os daily necessities for the whole population, and a 8 percent annual growth rate of financial revenues for the government would be assured.

A detailed report on this issue had already been submitted to the government for its reference, and we are happy that it played a certain role in the government policy-making on the current economic reform.

III. MACRO-CONTROLLED AND MICRO-ENLIVENED ECONOMY

China's economic system has now started moving apart from the system of utmost centralized planning, and it will probably never turn to the other extreme-Adam Smith's Completely Free Market. For such a big country as China with many different economically developed provinces, the attempt to make a perfect and all-compassing economic plan is nothing short of bureauratic utopia. On the other hand, if things are allowed to drift alone without status analysis and control of the overall economic system, it would surely lead to disaster. Therefore, to establish a micro-enlivened and macro-controlled economic system is the strategic goal of the current economic system reform in China. For example, China today is terribly short of energy. The shortage of electric power is up to 100 billion kwh, which makes many factories operate only four days a week. China possesses huge hydro-power reserves but only less than five percent has been developed. The discovered deposits of fossil energy rank third in the world, but the exploitation capacity is insufficient. The improvement of communication and transportation system is urgently needed. Agriculture calls for modernization and investment. In all of these areas, long-term investment plans must be worked out in accordance with the limited fund accomulation rates estimated for five to ten years to come.

By the way, in the course of economic reform, the concept of capital has changed radically. A century ago, Carl Marx said:" Capital is dead labour, it lives only by sucking living labours; Capital came into the world, dripping from head to foot, from every pore, with blood and dirt." However, the contemporary bankers alleged that: " Capital is far more important that your mother." The Chinese economists are now to explore some new concept and definitions between these extremes that would be applicable to this country.

Facing the shotage of fund, the government must put most sectors of the economy under macro-control in order to optimize the benefit of investment with constraint of national capital accumulation and social wealth growth. The results of system analysis indicate that the insufficiency of supply is the principle feature for the nest decades. Thus, the growth rate of supply capacity will determine the speed of China's economic development. However, the delay and dynamic effect of investment existing in different sectors would considerably complicate the policy-making of resource allocation. For example, food industry needs 2-3 years for construction, power plant, 5-10 years and 10 years for building a railway, etc. It is completely inadequate to make decision only on the basis of observation and intuitive judgement in any dynamic system. In recent years, the efforts of Chinese system scientists and economists have afforded the government a solid scientific foundation and enriched possible alternatives for its economic policy formulation.

In 1976, 17 countries and BNL and KFA jointly developed a linear programing model (MARKAL: MARKEL ALLOCATION) for energy policy evaluation, which has given evident impact on China's energy planning. Several Chinese universities have recently finished, by joint effort, a detailed dynamic analysis and projection on current

China's energy supply and future development. The result indicates that by 1990 the yearly energy demand will reach 900 million ton standard coal (against 700 million tons in 1984), 600 billion kw-hour electro-power; by the end of this century the annual demand will be increased to 1.4 billion tons standard coal and 1200 billion kwh elctro-power. In order to meet the need, the total amount investment for the remaining years is estimated as 20 billion US dollars, which is meant 10 billion dollars a year. In the way, the system analysists simply conclude that the government has to invest at the average of 10 billion US dollars each year into energy sector in order to quadruple the nation's GNP till the end of this century.

The State Planning Commission developed a model for more reliable planning. Their considerations included analysis of nineteen industrial sectors. This model consists of 254 dynamic equations of endougenous variables and 675 equilibrium equationswith 122 exogenous variables. A verification of this model by historical statistics from 1952 to 1982 shows that the coefficient of correlation has reached 0.95-0.99 and accuracy of short-term extrapolation up to 85%. In this way, the system science has provided the State Council with significant reference for its long-term planning of investments of different sectors.

It is no doubt that the vitalization of China's economy eventually depends upon the hard working of Chinese people encouraged by the reformed economic policy and the opendoor strategy. However, the system science will provide an indispensable guideline for government in its policy-making.

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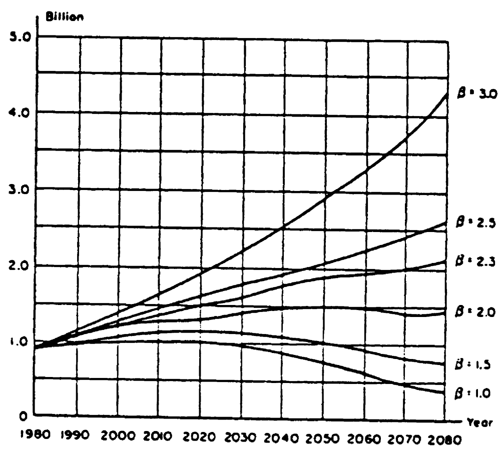

Fig. 1.

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NEW TRENDS IN SYSTEMS APPROACH BY THE INTERACTIVE USE OF MICROCOMPUTERS

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Abstracts. Placing stress on 1) the use of heuristics or experiences of an expert and 2) the interactive use of microcomputers or personal computers, some of the new trends are reviewed and discussed in systems approach especially in the field of interactive modeling of large scale systems, system failure diagnosis by use of knowledge engineering techniques, multiple criteria decision making and gaming system for complex problems.

Keywords. Systems approach; microcomputers; modelling; large-scale systems; failure diagnosis; decision theory; interactive programming; game theory; environment control; economics.

INTRODUCTION

A distinctive feature of a large-scale system is of its poor-definedness or ill-definedness, whereas systems we have dealt with so far are well-defined. Most real systems have this tendency. Social and economic systems are typical examples, which involve human beings as their important elements. Namely, in these systems, the factor of uncertainty plays a vital role, which turns out to be of great difficulty to deal with in mathematical formulations.

In discussing how an approach to ill-defined systems should be, we must consider the following two points.

The first point is how we modify various methodologies well established for well-defined systems. Indeed, methods and tools developed for a well-defined system are not necessarily useless for an ill-difined system, but eventually, what is able to bridge the gap between the real system and the theory must be heuristics that we human beings have. Therefore, an interactive systems approach in which human beings take part is strongly suggested.

The other point is that we have to pay attention to the capability of a computer which has been very quickly developed in this decade. In the past, much effort was concentrated on developing numerical and calculating capability, whereas in recent years we can expect an appearance of a computer which can not only manipulate symbolic notations but also process knowledge information by an inferential engine. An example of it is the on-going project of the fifth generation computer which was first proposed in Japan.

Moreover, as a direction of computer development, we have to point out the beautiful progress in micro-processors created by the development of micro-electronics technology. The smaller the cost/performance and the size of a computer becomes, the closer the distance between man and computer gets, and also the more user-friendly the use of the computer becomes.

Because of the reasons described above, the methodology is to be realized that supports decision making to resolve various problems such as structural identification, behavioral prediction and optimization of a large-scale system via taking mutual advantages of heuristics based on human expriences and the ability of a knowledge-based computer and via iterations of interactive processes between man and computer, especially microcomputer.

Based on this view, in this paper, we discuss the state of art in new trends in systems approach forcussing our attention on results of research groups headed by the authors, which include 1) interactive modeling of large scale systems, 2) system failure diagnosis by use of knowledge engineering techniques, 3) multiple criteria decision making and 4) gaming system for complex problems.

INTERACTIVE MODELING OF LARGE SCALE SYSTEMS

It is very difficult to formulate the practical model of a large complex system including human elements, for example, an environmental system, a traffic system, an economic system and other socio-technical systems. In this case, it is most important to combine the mathematical approach and heuristic one which is fostered through ripe experiences on field studies and expert knowledges of human being. A new modeling method, the interactive method of data handling (IMDH) is described, which aims to build the practical model of large scale systems by means of the communication between man and computer (Ryobu and Sawaragi, 1979, 1982).

IMDH is composed of two kinds of communication process. The first communication is qualitative and the second is quantitative. The outline of the modeling process is summarized in Fig.1:

Step-1 MAN arranges the information and classifies each relation among the variables into three types--"white", "gray" and "black". We suppose that a system is composed of variables $(x_1, x_2, \ldots x_n)$ and the model is expressed as the following equations;

$$x_i = f_i(x_1, x_2, \ldots, x_j, \ldots, x_n), \quad i=1\sim n, j=1\sim n, i\neq j.$$

If all of the relations between x_i and each of $(x_1, \ldots, x_n)$ are apparent we call them "white". If some of them are not apparent, we call them "gray". If all of them are not apparent, we call them "black".

Step-2 COMPUTER makes the linear equations with the method of least squares for "white" and with self-learnging organization for "gray" and "black".

Step-3 COMPUTER shows all the relations of the variables by the tier-structural di-graph, from these equations.

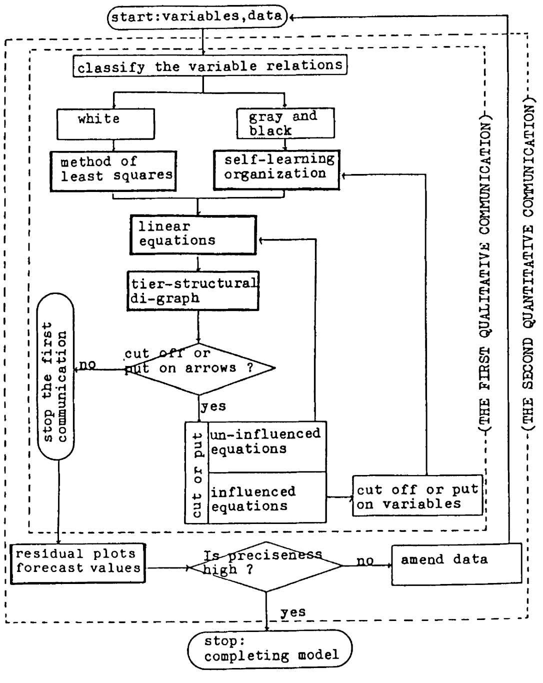

Fig. 1. Modeling process by IMDH

Step-4 MAN cuts off unnecessary arrows and puts on necessary ones in the di-graph. If there is nothing to do, MAN stops the first communication.

Step-5 Finding which variables are influenced on Step-4, MAN excepts the unnecessary variables or adds the necessary ones to the predictor variables. And then, return to Step-2.

Step-6 COMPUTER makes out the residual plots and the forecast values from the results (the equations) of the first communication.

Step-7 MAN picks up low-precise equations with reference to the residual plots or insufficient equations whose forecast values are much different from his experience, image and so on.

Step-8 MAN recollects the data or processes them by the method of data-changing, trend-exception, filtering and so on. And then, return to Step-1.

The characteristic points of this method are as follows. First, this method succeeded in shortening the modeling time, because of setting the self-learning organization in the computer, therefore, both a man and a computer become to be able to communicate with each other repeatedly and smoothly. Second, the tier-structural di-graph making a man possible to catch visually a bird's-eye view of the relations among the variables, and easy to find some unproper equations, he comes to understand steadily all the structure of system, discover something fresh and turn uncertainty into certainty. Thus through the process of IMDH, a man reflects his knowledge and experience enough in modeling, and on the other hand he also learns and develops himself. Therefore the more a man's knowledge and certainty of system increase, the more complete the model grows.

This method was successfully applied to build economic models of Kyoto Prefecture, Kyoto City and Shiga Prefecture from 1976 to 1985 (Ryobu and others, 1976-1985).

FAILURE DIAGNOSIS BY USE OF KNOWLEDGE ENGINEERING TECHNIQUES

The computer as a sequential computing machine is far superior to the human brain. There are, however, great many problems which cannot be solved by numerical processing only. Just suppose a specialist in some field try to solve a complex problem, he uses by all means his knowledge and experience as an expert as well as numerical computations. The computer so far has been incompetent in this kind of inferential processes in which it collects various information from its environment, understands it and then decides what to do. The research in the last 30 years to assist human intellectual activities by use of computers is called artificial intelligence. In 1977, Feigenbaum proposed the idea of knowledge engineering, which is a division of artificial intelligence and is more application oriented. The appearance and prosperity of knowledge engineering have been strongly supported by the very rapid progress of computers and the development of artificial intelligence oriented computer languages like LISP or Prolog. The knowledge engineering is, briefly to say, to make research on how human knowledge is represented and stored in a computer and how skillfully the stored human knowledge is retrieved and utilized.

An expert system is a subsidiary of artificial intelligence in which knowledge and experience of an expert in a specific field are stored in a computer and used as if the computer has almost the same ability of problem solving as the expert. The expert system is now the most prominent and prevailing system and thus is applied to various fields of engineering, medical, educational, economic, law and many other disciplines.

A distinctive feature of the knowledge engineering technique is that the knowledge which is necessary to solve a problem and the usage of the knowledge are completely separated. A collection of expert knowledge stored in a computer is called a knowledge base and the inferential process by use of the knowledge base is called an inferential engine. The independence of the knowledge base from the inferential engine makes the system very flexible, easy to manage and applicable to a variety of fields.

To check the possibility and validity of an expert system, the authors have constructed an expert system which can find causes of system failure in 1) a cooling system and 2) a start-up system of a marine diesel engine (Kumamoto and others, 1982, 1985). Novel and interesting points to be noted of the system are as follows:

(1) The system works in an interactive way. An operator sits up before a CRT terminal and answers a sequence of questions put by the computer, and eventually he obtains the cause of the trouble. This implies the system is not necessary for real time applications, rather it is quite fit for training non-experts.

(2) There are plenty of explanation functions. This means the computer can answer such questions asked by the operator as "Why did you conclude.....?", "How did you infer...?", "How can I fix it ?", etc. This helps training non-experts, too.

(3) It is very easy to add, to modify and to cut the knowledge base. This is due to the fact that the system is constructed on a general database management system, which contrasts to usual expert systems which are written in LISP or Prolog. This aspect well increases the

flexibility and adaptability of the system.

(4) The expert's knowledge is represented by a set of production rules or if-then rules. An if-then rule is expressed in terms of a prerequisite and a conclusion. Diagnosis of a plant failure is the search process of locating a cause in the form of a system component such as a valve or a pump through a successive classification of macro plant state into micro states. Successive classification of plant state is formulated by the following form of the if-then rule: If [plant state i] and (observable fact), then [plant state j].

(5) Two types of inference algorithms are implemented. The one is a forward or top-down algorithm and the other is a backward or bottom-up one. These algorithms are written in a database handling language, too.

(6) The system is implemented on a 16 bit personal computer. This implies that the system is portable, easy to tranfer and most of all not expensive.

(7) The cooling system failure diagnosis system has 22 rules and 15 basic causes of failure, and the start-up failure diagnosis system has 121 rules and 79 basic causes.

An example of the failure diagnosis process of the cooling system by operator-computer conversations is shown in Fig. 2. The underlined characters show operator's inputs to the computer. The input "?" denotes a question put by the operator to the computer: "Why do you ask me the fact?". The computer answers the followings. 1) the if-then rule currently being applied, 2) the proven states and facts in the prerequisite of the rule, and 3) a conclusion when observable facts turns out to be true.

MULTIPLE CRITERIA DECISION MAKING AND INTERACTIVE PROGRAMMING METHODS

In order to solve our decision problem by some systems-analytical methods, we usually require for the attainment-degree of objectives to be represented in some numerical terms, which may be of multiple kinds even for one objective. In order to exclude subjective value judgment at this stage, we restrict these numerical terms to physical measures, for example, money, weight, length, time and so on. As such a performance index or criterion for the objective P_i, an objective function $f_i: X \to R^1$ is introduced, where X and R^1 denote the set of alternatives and one dimensional Euclidean space, respectively. The value $f_i(x)$ indicates how much impact is given on the objective P_i by performing an alternative x. The impact modeling is performed to identify these objective functions from various viewpoints such as physical, chemical, biological, social, economical and so on. For convenience of mathematical treatment, we assume in this paper that the more of each objective function is preferred to the less. Now we can formulate our decision problems as a multiobjective optimization problem:

$$\text{Maximize} \quad f(x)=(f_1(x),\ f_2(x),\ldots,f_r(x)) \quad \text{over } x \in X.$$

Unlike traditional mathematical programming with a single objective function, there does not necessarily exist in multiobjective optimization problems an "optimal" solution in the sense that it maximizes all the objective functions simultaneously, and hence usually we are troubled with conflicts among objectives in decision problems with multiple objectives. The final decision should be made by taking the "total balance" of objectives into account. Therefore a new problem of value judgement, i.e., value trade-off arises. The evaluation modeling treats this problem peculiar to decision making with multiple objectives. Here we assume a decision maker who is responsable for the final decision.

In some cases there may be many decision makers, for which cases the decision problems are called group decision problems.

One approach to the evaluation modeling is to find a scalar valued function $u(f_1,\ldots,f_r)$ reperesenting the decision maker's preference, which is called a preference function in this paper: A preference function in decision making under risk is called a utility function, whereas the one in decision making under certainty is called a value function. Once we obtain such a preference function, our problem reduces to the traditional mathematical programming:

$$\text{Maximize} \quad u(f_1(x),\ldots,f_r(x)) \quad \text{over} \quad x \in X.$$

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-- CAUSE ISOLATION OF "ENGINE OVERHEAT" --

Q1   **ENGINE ITSELF IS NOT THE CAUSE**
       Is this true? T
Rule 1 deduces that:
COOLING SYSTEM IS RESPONSIBLE FOR OVERHEAT

Q2   **PRESSURE GAUGE READING OF F/W IS LOW**
       Is this true? F

Q3   **PRESSURE GAUGE READING OF F/W IS NORMAL**
       Is this true? T
Rule 10 deduces that:
ENOUGH COOLANT CIRCULATES IN F/W LOOP

Q4   **WARM-UP STEAM VALVE IS OPEN**
       Is this true? F

Q5   **TEMPERATURE READING OF F/W AT EXIT OF HEAT EXCHANGER IS
       HIGH**
       Is this true? ?

/// I am trying to use /// Rule 12
/// I already know that: ///
ENOUGH COOLANT CIRCULATES IN F/W LOOP
/// If you inform me further that: ///
TEMPERATURE GAUGE READING OF F/W AT EXIT OF HEAT EXCHANGER IS
HIGH
/// Then I will conclude that: ///
HEAT EXCHANGER WORKS POORLY

Q5   **TEMPERATURE GAUGE READING OF F/W AT EXIT OF HEAT
       EXCHANGER IS HIGH**
       Is this true? T
Rule 12 deduces that:
HEAT EXCHANGER WORKS POORLY

Q6   **TEMPERATURE GAUGE READING OF S/W AT EXIT OF HEAT
       EXCHANGER IS LOW**
       Is this true? ?

/// I am trying to use /// Rule 13
/// I already know that: ///
HEAT EXCHANGER WORKS POORLY
/// If you inform me further that: ///
TEMPERATURE GAUGE READING OF S/W AT EXIT OF HEAT EXCHANGER IS
LOW
/// Then I will conclude that: ///
DIRTY HEAT EXCHANGER AND HENCE LOW HEAT EXCHANGE RATE IS
RESPONSIBLE FOR OVERHEAT

Q6   **TEMPERATURE GAUGE READING OF S/W AT EXIT OF HEAT
       EXCHANGER IS LOW**
       Is this true? F

Q7   **TEMPERATURE GAUGE READING OF S/W AT EXIT OF HEAT
       EXCHANGER IS HIGH**
       Is this true? ?

/// I am trying to use /// Rule 14
/// I already know that: ///
HEAT EXCHANGER WORKS POORLY
/// If you inform me further that: ///
TEMPERATURE GAUGE READING OF S/W AT EXIT OF HEAT EXCHANGER IS
HIGH
/// Then I will conclude that: ///
LOSS OF COOLANT OCCURS IN S/W LOOP

Q7   **TEMPERATURE GAUGE READING OF S/W AT EXIT OF HEAT
       EXCHANGER IS HIGH**
       Is this true? T
Rule 14 deduces that:
LOSS OF COOLANT OCCURS IN S/W LOOP

Q8   **S/W CONTROL VALVE IS CLOSED**
       Is this true? F

Q9   **S/W COOLANT PUMP IS NOT OPERATING**
       Is this true? F

Q10  **S/W COOLANT PUMP IS OPERATING**
       Is this true? T
Rule 17 deduces that:
LOSS OF COOLANT OCCURS IN S/W LOOP WITH PUMP OPERATION

Q11  **S/W DISCHARGE VALVE IS CLOSED**
       Is this true? F

Q12  **PRESSURE GAUGE READING AT SUCTION VALVE OF S/W COOLANT
       PUMP IS LOW**
       Is this true? T
Rule 19 deduces that:
BLOCKAGE OF STRAINER OR CLOSED SUCTION VALVE OF S/W COOLANT
PUMP IS RESPONSIBLE FOR OVERHEAT

*************************************************
This is the cause of "ENGINE OVERHEAT".
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Fig. 2. Example of failure diagnosis process

Another popular approach is the interactive programming which performs simultaneously both the search of solution and the evaluation modeling:

In this approach, without identifying the preference function, the solution is searched by eliciting iteratively some local information on the decision maker's preference. We shall discuss interactive programming methods in more detail in the following.

As stated above, the aim of interactive programming methods is to support the decision maker to make their decision easily in a cooperative way with computers. Therefore, it goes without saying that it is very important in developing these interactive methods to make the best use of the strong points of man and computer. A computer is strong at iterative computation in routine and can treat large scale and complex computation with high speed. On the other hand, a man is good at global (but, possibly, rough) judgment, pattern recognition, flair and learning. With these points in mind, we impose the following properties on desirable interactive multiobjective programming methods:

(1) (easy) The way of trading-off is easy. In other words, decision makers can easily grasp the total balance among the objectives.
(2) (simple) The judgment and operation required to decision makers is as simple as possible.
(3) (understandable) The information shown to decision makers is as intuitive and understandable as possible.
(4) (quick response) The treatment by computers is as quick as possible.
(5) (rapid convergence) The convergence to the final solution is rapid.
(6) (explanatory) Decision makers can easily accept the obtained solution. In other words, they can understand why it is so and what it came from.
(7) (learning effect) Through the interaction process, decision makers can learn many things, for example, gaps between their desires and the real world, and mutual understanding of participants in group decisions.

Interactive programming methods seem promising in particular for design problems. However, in applying ordinary optimization techniques, we often encounter some difficulties: For example, in structural design problems such as bridges, function forms of some of criteria can not be obtained explicitly and their values are usually obtained by complex structural analysis. Similarly, values of criteria in design of camera lens are obtained by simulation of ray trace, and moreover the number of criteria is sometimes over one hundred. From such a practical viewpoint, many existing interactive optimization mehtods require too many auxiliary optimizations during the whole interaction process. Moreover, some of them require too high degree of judgment to decision makers such as the marginal rate of substitution, which seems to be beyond man's ability.

In many practical situations, decisions seem to be made on the basis of satisficing rather than optimization due to the limit of human ability and available information. However, rather than mere stisficing, it is more disirable to ensure that the obtained solution is satisfactory and in addition there is no other feasible solution superior to the obtained solution in terms of all criteria. For example, let us consider a case in which a decision maker ordered two designers to design some industrial product. Almost at the same time and almost at the same expense, these two designers completed their designs, which were all satisfactory to the decision maker. However, one of designs is superior to the other in terms of all criteria. In this case, it seems no doubt that the decision maker adopt the superior one. From this observation, we recently suggested "Satisficing Trade-off Method (Nakayama and Sawaragi, 1984a, 1984b). The outline of the satisficing trade-off method is as follows:

If the given aspiration level is feasible (i.e., there is a possibility to improve all criteria), then by solving an auxiliary Min-Max problem we show a Pareto solution which distributes the equal improvement to each criterion. On the other hand, if the aspiration level is not feasible, then by solving the same kind of Min-Max problem we show a Pareto solution for which each criterion shares an equal sacrifice. If the decision maker is not satisfied with the shown Pareto solution, then he answers his new aspiration level in view of some available trade-off information such as the Lagrangian multipliers in the auxiliary Min-Max problem. Repeating such a procedure, we finally obtain a satisfactory Pareto solution for the decision maker (Fig. 3.)

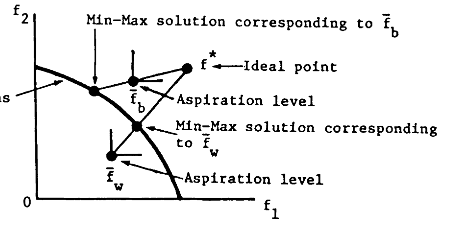

Fig. 3. Satisficing trade-off method

The satisficing trade-off method requires only the aspiration level of the decision maker which is very easy to answer. Therefore, it is very intuitive, easy and simple to carry out. Throughout many experiments, we have observed that the satisficing trade-off method holds almost of all desirable properties stated above. In addition, the method is also expected to be applicable to group decision problems as a tool of negotiation, because the aspiration level of each criterion can be considered the aspiration level of each person in the group. Many practical applications in the real world could encourage us to sophisticate the methodology in the future which is robustly flexible to multiplicity of human value scope.

GAMING SYSTEM FOR COMPLEX PROBLEMS

Gaming is a method that has been used with success for a variety of complex problems. Decision makers involved in a refined game could have a realistic situation in which they must collectively consider their strategies. Therefore, gaming appears to be a promising tool to deal with complex problems in which human decisions have far-reaching effects on others.

The authors believe that recent development of microcomputer will give a great impact on gaming techniques. We have been studying gaming approach by microcomputer in order to solve various complex environmental problems such as acid rain problem in Northwestern Europe, and we have made several microcomputer-based games (Baba and others, 1983, 1984, 1985).

Fig. 4 shows our microcomputer gaming system being used in our gaming experiments.

We can enumerate several advantages of this microcomputer gaming system.

(1) Since microcomputer calculates fast, players