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Approaches to the Study of Decision-Making Relevant to the Firm

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APPROACHES TO THE STUDY OF DECISION-MAKING RELEVANT TO THE FIRM *

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In this paper some of the difficulties in utilizing much of economic theory as an aid to the study of decision-making at the level of the firm are reviewed. New theories, techniques and experimentation aimed at overcoming these difficulties are then discussed. The area covered is, of necessity, broad. No attempt is made to provide more than an indication of the type of work in progress and the nature of the problem to which it is addressed. References are supplied for those wishing a more detailed exposition of the many topics noted here.

I. The Purpose of and Difficulties with Micro-Economics

In the past few years a series of new subjects and a host of new terminologies have sprung up in the border areas between economics, industrial management, industrial engineering and psychology. Viewed from the university, the manifestations of change have come in the growth of interdisciplinary work under the broad category of the behavioral sciences. Viewed from industry, the growth of management science and operations research have been the bellwethers. They have served as the interlink between the firm, its concern for policy and specific problems, and a more academic approach to micro-economics,

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which is the study of the role of individual economic decision-makers (firm or consumer), including interactions between several individuals.

It is natural to suspect that this proliferation of new work has taken place in order to fill a need not satisfied by the previously created body of knowledge. The limited success in attempts to apply micro-economic theory to the firm has called for a re-examination of the theory and its assumptions.

Until a few years ago the major applications of economic theory were aimed primarily at macro-economics, or consideration of the economy as a whole studied in broad aggregates. Micro-economics has been and to a great extent remains a jungle of special assumptions, special cases, unsatisfactory measurements and tenuous theorizing.

The success of the application of macro-economics have been considerable and a growing body of both descriptive and normative macro-economics exists today. The descriptive theory attempts to describe how the economy behaves, and given the observations on behavior, predictions can be made about future behavior. The normative theory suggests how people "should" behave and as such can be linked up to political and social theories to provide an economic basis for the planning of policy. The literature on macro-economics is large and well known. No further discussion of this topic is given.

A late starter in the revival of increased interplay between the discipline of economics and the functioning of the economy has been micro-economics. The neo-classical theory of the firm, as exposited by Alfred Marshall, provided an elegant theoretical mechanism for describing the distribution of resources among firms in an industry, the long-run development of an industry and the evolution of its price structure. This theory was based on the concept of a competitive market, i.e., a market where all firms are sufficiently small to be able to disregard the specific interaction between any two of them, where adjustments, new investment, liquidation, hiring and all the other myriads of actions which go to make up the firm are accomplished smoothly, without restriction and in an open market governed by a smoothly functioning price mechanism known to all parties. This theory had the firm as its "atom" or decision-making unit. Little or no attention was paid to internal structure of the firm or the many other micro-economic complications which will be discussed later.

This micro-economic theory of the firm within an industry has provided models for the consideration of long-run resource allocation in parts of an economy where the forces of pure competition tend to dominate other considerations. Keynes' sardonic observation that "in the long run we are all dead," calls to our attention that the worth of a theory is determined by whether it addresses the relevant problems and provides information relevant to the problems at hand. The

Marshallian theory of the firm is only sufficient to offer very limited aid to individuals running firms to those concerned with the control of industry.

The reasons for this inadequacy are well known. The simplifications made to obtain the competitive model of the firm are too drastic to provide either a normative or descriptive micro-economic theory of more than limited use to the firm. Most industries contain large multi-product firms whose actions have considerable influence on each others' destinies. They act in a haze of incomplete information or misinformation not accounted for by the competitive theory. There are many pressing internal problems and conflicting goals caused by corporate structure. These alone are sufficient to restrict the use of neo-classical theory of the firm in coping with problems of industrial organization or decision-making at the level of the firm or market.

The active participation of economists in advising firms has been increasing. The role of the economist and the use of his training in principles of micro- and macro-economic theory for business planning has ably and entertainingly exposited by Sidney Alexander in a discussion entitled "Economics and Business Planning." 1/ However, the current trends in the development and application of micro-economic theory are being formed by individuals among whom the economists represent only one of many disciplines. The individuals engaged in operations research and management science include mathematicians, engineers, psychologists,

physical scientists and others, as well as economists.

In spite of the varied backgrounds of those working in operations research or management science, their interests are primarily focussed upon the decision-making processes at the level of the firm. This may be regarded as an interest in the development of normative micro-economics. They are engaged in a search for methods to aid the decision-maker in a business in deciding how to act. Parallel developments are taking place influencing descriptive micro-economics. The new investigations by psychologists and others are yielding insights which lead to new and considerably different descriptions of economic man. The growth of new measurement devices and data processing systems has changed considerably our ability to view and describe the environment. The latter development complements the former, for as the student of, or participant in the firm knows, the decision rule may be excellent, but if the description of the environment is incorrect the application of the rule may be disastrous.

There have been many definitions of economics. Jacob Viner has suggested that "economics is what economists do." Herbert Simon has suggested that economics is "the science that describes and predicts the behavior of several kinds of economic man -- notably the consumer and the entrepreneur." 2/ Alexander notes that "economics is the study of the fundamentals governing business, and it stands in the same

relationship to the practice of business as knowledge of physical laws and facts to the practice of engineering." 3/ Another definition offered is that economics is the study of the optimal allocation of scarce resources (this might also fit psychiatry).

The statements of Simon and Alexander are sufficiently operational that the need for more detail to fill out these condensations becomes transparent as soon as they are used by anyone wishing to understand economic problems. In spite of the desire of many busy individuals for condensations, complex concepts often require complex expositions. Thus to most seekers of capsule knowledge, Professor Viner's tautology serves as the appropriate reply.

The fourth definition has been more traditional to economics and can be made somewhat more specific to cover the standard economic theories of choice and decision for the consumer and the firm. Microeconomic theory involves the study of the optimization process for a "rational" individual decision-maker -- an economic man -- confronted with a completely known set of certain or probabilistic outcomes. Economic man, as is implicit in the theory of consumer choice or of price in competitive markets, is a rational, omniscient, lightning-quick calculator resolutely bent on maximizing a known objective.

For some descriptive purposes or over-all policy decisions this model of economic maximization contains sufficient truth to be

worth considering. However, it is not a good model of the individual decision-maker with limited time at his disposal, limited perceptions and computing ability and knowledge of only a few alternatives all of which involve differing degrees of risk. Hence, when the questions we wish to ask involve decisions at the level of the firm, in many instances we will need different and/or richer models than are provided for by the concept of rational economic man.

The limitations of the economic view of man have been noted from many quarters in the behavioral sciences. Freud has suggested that it is only small decisions that are made rationally. The decision to select one out of several sizes of eggs at a super market may be adequately modeled by the theory of consumer choice under complete information. The decision to build a multi-million dollar plant may be more adequately modeled by a theory of the monument-building propensities of retiring moguls than by the economic theory of investment.

Kenneth Boulding, discussing the problem of economic behavior, 4/ discusses the role of an "heroic man" whose ethic calls for action without calculation of cost. He suggests that this man is the motivator of saints and soldiers. "Without the heroic, man has no meaning. Without the economic, he has no sense."

Laswell, writing about the decision process from the viewpoint of law and political science, 5/ maps out a dynamics involving seven categories of functions which although referring to an organization could equally well refer to the individual.

The psychiatric, legal and political aspects of decision processes are not discussed further because of limitations of knowledge and space.

Starting with the model of economic man confronted with choices resulting in known certain outcomes we note the new mathematical extensions of his abilities. Statistical uncertainty is introduced. (I.e., although the individual is not certain about an outcome he is given a probability of its occurrence, for example, the occurrence of a number in roulette.)

In Section II the implications of the ability to compute and methods of dealing with this type of uncertainty are considered.

The ability to maximize is hampered if more than one individual with goals that are not identical are involved. Section III considers rational man in conflict.

Implicit in the previous two Sections is the assumption that the individual or firm knows what he or it wishes to maximize. The value and plausibility of this as an assumption are discussed and some problems in dealing with goals are noted in Section IV. Attempts have been made to construct a theory of organization which would help to account for many of the difficulties encountered in describing the goals of a firm, although little success have been had.

In Section V the lack of knowledge of the individual about his environment is considered. The limitations in his ability to perceive are noted and consideration is given to problems of search, learning and obtaining information from the environment.

Section VI is devoted to a discussion of new experimental and empirical methods which promise to be of importance in the study of decision processes.

It is easy to proliferate the distinctions and multiply the models of man in a manner as liberal as the supply of characters in Tolstoy's War and Peace. The problem is to do so in a manner that provides more than casual aid to the understanding of the decision-making process. The following areas of study are among those which are currently contributing actively to this understanding, which are referred to in the subsequent sections.

Economic theory 6/ and statistical decision theory 7/ are among those which provide advice to economic man.

Game theory 8/, games against nature 9/, bargaining and bidding help us to consider the actions of man in conflict or collusion.

Empirical investigation 10/ and organization theory 11/, among others, cast light upon the nature of goals.

Work in experimental psychology 12/ 13/, information theory 14/ and artificial intelligence 15/ is expanding our understanding of man as an adaptive creature making his way in a partially known environment.

Experimental games 16/, business gaming 17/ and simulation 18/ are being employed as experimental and empirical tools to help to validate some of the theories noted above and to aid in the description of complex organizations.

There is also a broad range of work encompassed under the general titles of operations research, management science, systems engineering 19/, and applications of computers, as well as a growing literature on diplomatic, political and economic negotiations which are not mentioned specifically.

II. Programming Man -- A Direct Descendant of Economic Man

Before the atmosphere is clouded and the well-defined "dismal science" of the economists is replaced by a miasma encompassing the many facets of decision-making as viewed by the behavioral sciences, the more complex models of rational decision-making are considered.

Economic Decision-Making Under Certainty With Many Choices

If a situation can be modeled so that it presents a well-defined but possibly highly complicated choice problem involving a great number of specified alternatives of known worth, linear programming and allied methods 20/, have been developed so that optional solutions which were previously too difficult to calculate can now be found. These have direct application to the selection of alternative production processes under capacity limitations, to product mix and transportation problems and other specific problems of the firm. With some modifications 21/, linear programming can be made to deal with conditions of uncertainty in the form of a probabilistic knowledge of the environment. With the aid of mathematical techniques and computers, the potential scope of economic man has been enlarged. This reprieve, however, is not too

substantial, analytical methods are often not sufficient and the number of alternatives to be faced in many instances even without uncertainty is so large that the effect of the swiftest computer can be quickly nullified if all the alternatives are to be considered.

Queueing, Inventory, and Other Relatives of Statistical Decision Theory

By introducing probability considerations, an attempt can be made to extend the economic theory of choice to conditions involving uncertainty. The heroic assumption must be made that the situations to be modelled are such that it is valid to utilize probability theory. This has given rise to discussions concerning subjective probability 22/, and a large literature on probabilistic preferences and the theory of utility. 23/ Problems concerning gambling and risk preference have been examined and alternatives to the modern economic man, who maximizes expected utility, have been suggested. For example, Savage has offered a man who wishes to minimize regret. In other words, after the event, when he looks back he wishes to have acted in such a manner that he will be the least sorry concerning the outcome. Shackle 24/, has constructed a "potential surprise function" which he feels dominates many major decisions which must be made in face of uncertainty which cannot be adequately portrayed by probability considerations.

In spite of the limitations of probability models, the trades of operations research and industrial statistics have, however, flourished

by applying normative models of economic man acting under probabilistically portrayed uncertainty. Inventory theory models, sequential sampling and various queueing problems have been actively applied. Yet these efforts tend to reinforce Freud's comments. For the most part they involve the application of decision-making theories to decisions delegated by management rather than casting light upon managerial decision-making itself.

One area in which the applications have been fewer but the implications deeper is that of dynamic programming. 25/ This methodology deals with situations where at each period the decision-maker chooses an action which influences a sequence of events stretching off into the possibly indefinite future. In subsequent periods he has the opportunity to modify the effects of previous decisions by current action. Although this theory still deals with statistical uncertainty and mathematical expectations, the decision rules generated as dynamic program solutions have more of the flavor of over-all long range strategic decisions.

III. Rational Man in Conflict

Theories of Games

Possibly the most ambitious attempt to develop the concept of rational man has been with the theories of games. The work of von Neumann and Morgenstern 26/, helped to create many more problems than it solved. But in doing so, it provided a language for the study of decision-making (the description of the so called "extensive form" of a game 27/).

This includes well-defined concepts of information, choice and strategy.

The need for a precise language to describe situations of choice and conflict becomes clear when we consider even such relatively simple problems as chess. Furthermore any attempt to compute a method of play in chess highlights some of the difficulties inherent in theories of rational decision-making. There are billions of alternative strategies to be considered. Methods must be found for scanning them in broad aggregates. It is to the finding of these methods that the new topic, sometimes termed as "artificial intelligence" has been addressed; this is discussed further in Section V. It is not enough for a decision-maker to know that his problem is theoretically perfectly solvable if he is willing only to search through and examine some billions of alternatives each of which involves much computation. He must have the time and ability to do so, or employ an alternative approach. The end to such a procedure has been illustrated in a limerick:

"There was a young fellow of Trinity
Who solved the square root of Infinity
But it caused him such fidgets
In counting the digits
He chucked Maths and took up Divinity."

It was not only difficulties in the examination and calculation of strategies which were highlighted by von Neumann and Morgenstern. Their analysis helped to isolate problems standing in the way of the development of satisfactory theories of decision in situations involving more than one

individual. They offered two theories for the behavior of individuals. One for a special class of situations involving only two participants with diametrically opposed goals and the other for more general situations involving two or more decision-makers whose goals are not necessarily totally opposed.

The first theory has gained many adherents as a normative theory of behavior for such situations. If this writer were found in a situation which could be portrayed adequately as a two person strictly competitive game, provided it were possible to do the computations he would be guided by this normative theory. There are many military problems which can be modelled as competitive games and applications of the theory have been made. Unfortunately important problems in the theory of the firm cannot be addressed in this manner.

The second theory of von Neumann and Morgenstern has been far less satisfactory. Not because of a lack of formal appartus or mathematical elegance (on the contrary the apparatus is formidable); but because it does not appear to provide models relevant to most of the problems of decision-making in the firm or in other situations. Many theories of behavior of individuals acting in an environment containing many others now exist. Today there are twenty-odd theories of behavior in n-person games. None of which is universally satisfactory. However, some of them have value in the analysis of special situations such as bargaining; competition among few firms; voting and the study of the formation of power blocs.

The attempts to construct adequate theories of many person games have highlighted difficulties elsewhere; for example, attention has been called to the meaning and the role of information in situations of conflict.

Often the possession of special information is the key to a market. There is an old saying in bridge that a peek is worth two finesses. In many situations the major weapon of competitors may be special knowledge or information. In organizations, for example, one of the forms of control exerted by a subordinate is his ability to filter and bias the information he passes on to higher levels in the organization. The very multiplicity of theories for the solution of games is an illustration that unsubstantiated mathematical conjectures are unlikely to serve as an adequate substitute for a systematic study of human behavior in its economic or other environments. The new mathematical methods have led to a new stress of the need for experimental and other empirical work on decision-making. The power of the methodology has made it easier to see the weaknesses and the gaps in the theories.

IV. Goals and Organizations

Who Maximizes What?

The individual rational decision-maker of economic theory has been on the one hand a singularly simple individual, and on the other hand an extremely complex one. His pristine simplicity comes about in his good fortune in knowing what he wants. As an entrepreneur owner of a firm, his economic role is to maximize profits. The effects of life, death, cost accountants, partners or boards of directors and stockholders are of little significance to this economic man.

The picture of the individual profit maximizer is not sufficient to provide either a descriptive or a normative model of the decision-maker

in the firm. For example, the concept of profit is extremely difficult to define and once defined is generally hard to measure.

Some of the difficulties in defining the goals of the firm are illustrated in an unpublished study made by this writer of the statements of corporate aims by twenty-five corporations, seventeen of which are among the five hundred largest manufacturing firms. They reveal a blend of economic, political, social, and ethical considerations which provide a self-image considerably different to that of economic man. The sources and detail of this material vary considerably as is indicated below.

Titles or captions of the statements of objectives are:

> "Our Aim; Basic Objectives; Objectives; Creed; The Policy; Company Objectives; Company Policy; Principles; Our Credo; The Company's Philosophy; General Corporate Policies; Philosophy; Statement of Policy; and General Objectives of Management."

The sources include statements from chairmen, both in the financial press and elsewhere; statements from management guides and manuals; approved releases by the board of executives; notes by company presidents; and statements from company reports.

The contents have been classified under the headings given below. These are accompanied by numbers indicating frequency of reference in the 25 statements.

Personnel	21
Duties and Responsibility to Society in General	19
The Consumer	19
Stockholders	16
Profit	13
Quality of Product	11
Technological Progress	9
Supplier Relations	9
Corporate Growth	8
Managerial Efficiency	7
Duties to Government	4
Distributor Relations	4
Prestige	2
Religion as an Explicit Guide in Business	1

Selznick has correctly observed [28] that "once an organization becomes a going concern with many forces working to keep it alive the people who run it readily escape the task of defining its purposes." Possibly the vagueness of some of the objectives noted above represent an attempt to escape defining corporate purposes. Yet, other work has indicated that the "cultural milieu" of a business provides considerable conditioning for management goals. Recently work on comparative management in different countries has highlighted

the different objectives of economic organizations. For example, the relations between the worker and the executive in the Japanese factory contrasts significantly with ours. 29/

The theorist may claim that the multiplicity of vaguely defined goals are merely a subterfuge for disguising the aim of long-run profit maximization. It is easy to construct mathematical models which treat all stated goals other than profit maximization as boundary conditions. It is not so easy to demonstrate that this provides the most satisfactory model of the behavior of the firm. It has been suggested that a useful model of behavior can be obtained by assuming that the object of the firm is to provide "the good life" for its executives. Though this may be an initial appeal it is possibly even harder to define operationally than most of the categories presented above.

Simon has suggested that economic man be replaced by a "satisficing man." 30/ This individual living in a complicated, vague and uncertain world does not attempt to maximize but is content if his current levels of aspiration are met. Behind this model of the decision-maker are considerations of incomplete information, conflict, limited ability to process information, limited perceptions and desires, combined with an ability to learn and to modify the desires. Unfortunately, just like his doppelganger homo sapiens, "satisficing man" is hard to deal with, and not as well defined as he appears to be at first sight.

Organization Theory

Organization theory is more a set of words than a reality. The work in many areas discussed such as experimental gaming, game theory,

bargaining and business games, -- has direct bearing upon the development of a general theory of organization. In spite of the wealth of writings over the centuries from many different disciplines as the military, political science, law, sociology and anthropology, few general principles concerning organizations exist. Modern works as typified by Barnard, [31] and March and Simon, [32] and Argyris [33] provide insights and food for thought but do not supply a full or satisfactory theory. The age of the organization chart is still with us and although the old chestnuts concerning span of control may no longer be believed (if they ever were), few new maxims have come to take their place. The observations of an ancient Chinese general writing in the Fifth Century B.C. [34], or an Arabian administrator writing in the Fourteenth Century on problems of organization, [35] have in many parts a contemporary ring. A modern writer on problems of organization would be hard put to exceed these contributions.

At a somewhat more restricted level, Marschak and Radner, [36] have confined themselves to the development of a theory of teams. They consider only situations in which the several individuals involved have identical goals and no problems of inter-personal conflict. Their major investigation is centered upon problems of the design of optimal communication systems and information handling procedures to optimize the performance of the team.

V. Information, Learning and Intelligence

Learning

As more recognition is given to the nature of the individual as a decision-maker with limited perceptions operating in an uncertain environment, the influence of and the need to understand the work of psychologists becomes more important. The developments in learning theory by Estes,[37] Bush, Mosteller,[38] Siegel,[39] and others deal with many of the same problems met with in the design of forecasting systems with self-correcting feedback, i.e., systems which are able to learn from their errors. Probably one of the most valuable sources of data that many firms could tap, but few utilize is a record of forecasts as compared with actual events. Memory is usually selective, hence it becomes difficult to find out the degree of error actually present in a forecasting system, or the pattern of learning without a careful compilation of these statistics.

Another topic in which the learning phenomenon presents itself in an important way is competitive behavior in a dynamic setting. For example, the conditions resulting in stable markets with price leadership implicitly or explicitly are interlinked with stimulus and response learning patterns. Much of the economic literature describing lengthy chains of action and reaction between competitors in limited markets is of this variety.

The business game exercises discussed below also involve learning. In general it takes the participants several periods before they are able to develop a concept of the nature of the market within which they are

operating and even longer to be able to anticipate the behavior of their competitors.

Much of the work in the development of a theory of learning has involved a simple binary choice experiment; so called because the subject is required to choose between two items. For example, he may be confronted with two lights on a wall and be asked to predict which one will be illuminated next. The experimenter may use a random sequence to decide upon which of the lights will go on or he may arrange for his choice to depend upon the actions of the subject, or many other conventions can be utilized.

Depending upon the convention and the manner of reward used, there now exists several theories to explain the behavior of the subjects. For example, under conditions of no or low monetary reward the Estes theory predicts that the subjects will track the relevant frequencies of the lights. Siegel has obtained results which indicate that if there is a sufficient monetary or other utilitarian incentive, the game theoretic predictions will be borne out. Furthermore, the speed of learning is apparently dependent upon the size of the incentive.

The binary choice experiment can be converted into a game situation by employing two subjects and letting the frequencies of the events depend upon their interactions. Even though this is a vast oversimplification of economic competition, many of the fundamental problems common to any learning situation are already present

Information Theory

The word "information" has been one of the most used and abused words in the writings on decision-making and planning in industry, the military, and elsewhere. There are many tales of the conscientious research worker who produces a 500 page detailed report on a market study only to be told by his immediate superior to "boil it down" to 10 or 20 pages for him. To then further "boil it down" to 2 or 3 pages for the next man in the heirarchy, and to finally summarize the thing in a paragraph for the top decision-maker.

The moral is simple: what is "information" at one location in an organization is not necessarily "information" at another location. In order to seek a measure it is necessary to consider the relationship between the input of words, symbols, noises, or other stimuli, and the output. The detailed market study is of little or no use to the man who is not able to read the presentation in that form. For value to be obtained, either the transmission system must be modified or the receiver or decoder must be changed, or possibly both. For optimal performance they must be compatible.

In practice today it is customary for the research workers and the consultants to claim that their results and advice are emasculated by over-condensation and over-simplification. On the other hand, the executives claim that many reports they receive are too long and full with irrelevant details. As more is learned about decision-making and as the newer breeds of business school graduates obtain positions in industry both the nature of the information supplied and the ability of the executives to interpret it, will change. For example, contrast the attitude toward statistics and

probability today from that of 20 years ago. In some instances "one number" forecasts have already been replaced or enhanced with considerations of confidence intervals.

Although the attitude illustrated by: "these graphs and charts are too confusing, call the Treasurer and let's have a peek in the till," may be with us for a long time, the advent of the formal study of information has already made inroads into the understanding of the role of information in a decision system.

There are at least three areas in which work has been progressing. All of them are of relevance to the firm. They are respectively in computer technology, psychology and economic or industrial decision systems.

Claude Shannon in his concern with problems of communication,[40] was the inventor of the fundamental unit of measure used in the evaluation of the capacity of systems to transmit and receive symbols. His measure of information is a purely technical one and he is not concerned with semantics of the symbols being transmitted. In this theory there is no interest evinced as to what the symbols mean.

If a human being is regarded as an information-receiving device several results in experimental psychology cast light upon man's ability to discern. In a celebrated and highly readable article entitled, "The Magical Number 7, plus or minus 2," George Miller, [41] has discussed the ability of individuals to distinguish between stimuli. He observes that in experiments with loudness, taste, perception of visual position and several other stimuli; that the ability of an individual to make distinctions is limited to about seven items. The "channel capacity" of the individual is

such that he does not appear to be capable of distinguishing between more than seven degrees of loudness, or pitch or salinity, etc. If, however, the individual is confronted with objects which provide more than one clue, for example, the size and the color of a set of squares, his capacity increases. However, even there limitations soon set in and given many different clues for each item, there appears to be an upper bound at around 150 items.

Miller notes that it is probably "only a pernicious Pythogorem coincidence" that the span of judgment is seven which adds yet another item to the list of "the Seven Wonders of the World, the Seven Seas, the Seven Deadly Sins, the Seven Daughters of Atlas in the Pleiades, the Seven Ages of Man, the Seven Levels of Hell, the Seven Primary Colors, the Seven Notes of the Musical Scale, and the Seven Days of the Week." He omitted the Seven Man Span for Management Control. In light of these considerations it is natural to ask even if we were able to generate any number of reports and alternative proposals, how many alternatives should be submitted to an executive? How many differences can a consumer perceive between the various products being offered? How many different wines can the amateur wine taster distinguish?

Miller discusses several methods whereby individuals are able to increase their ability to discern. These involve considerations of memory and of the complex process of "coding." In industrial and military systems, especially, the design of optimum messages or signals, which is the problem of coding, is of prime concern.

Another set of closely related problems appear when information is looked at from the viewpoint of the economist. Marschak notes that "to an

economist it seems natural to call value of information the average amount earned with the help of that information"[42]. This immediately leads to considerations of demand and supply prices for information. For example, an as yet unsolved but at least well-formulated problem concerns the design of incentive systems to pay forecasters in such a manner that it will always be in their interest to supply the decision-maker with information of optimal value to him[43]. That this has not yet been achieved is easily observed by the plethora of newsletters, market forecasts, tipster sheets and retrospective financial forecasting which can find a market.

Computers and Artifical Intelligence

With increasing frequency the newspapers and business journals are filled with prophecies and warnings concerning the brave new world and the doom of middle management who will find themselves displaced by computers. As long as an organization has at least three tiers of management by definition middle management will not cease to exist. The odds are large, however, that within the next twenty years many functions which were regarded as within the domain of middle managers of the current variety will have been automated.

As machine programs become more intelligent the automation will spread from more to less routinized jobs. Intelligent machines exist today and the effort by man to make them more intelligent constitutes an important advance in our understanding of the nature of the creative process and of human intelligence itself.

The achievements of the intelligent machines are certainly not great when compared with those of human decision-makers. Nevertheless, they have already cast light on the decision processes. No machine has yet run a business although most of them spend most of their time meeting payrolls. The few intelligent machines play a good game of checkers, a mediocre game of chess, write indifferent music, invent names for new substances, and prove theorems in geometry and in logic.

Even given a machine's capacity to do computations it is impossible for it to make a complete search of the alternatives in a game such as checkers or chess. The programs used by machines to play these games recognize this limitation. No attempt is made to carry out an exhaustive search. Some aspects of openings, and end games are memorized, but beyond that the machine plays according to general principles. The so-called techniques of heuristic programming provide the machine with patterns of exploration, and general rules of learning and evaluation. From one point of view the complexity of the decision process in playing chess may appear to be considerably smaller than that in making a decision in the running of a firm. Nevertheless, as relatively little is known about either process, a gain in the understanding of even the simpler situation represents an advance. The use of machines to aid in production scheduling, inventory control, and linear programming is already well established. In some plants today machines are solving these problems routinely, while in other plants human beings are solving the same type of problem. The roles of many "creative" design engineers have now been taken over by

computers in the design of heavy electrical equipment. In all of these instances man has had to understand the nature of the process used to enable the machine to solve the problem.

Whether machines are capable of thinking or of making better decisions than human beings or of "being creative" depends upon what we mean by thinking, decision-making, and crea ivity. In general, when we use these words they are ill-defined. Much of the work in teaching machines how to think has aided in teaching their mentors. An excellent non-technical summary of thought on machine-thought is given by Daniel McCracken in a progress report on machine-intelligence [44].

Experimental Gaming

The use of games as a research device to study economic decision-making has been a new development of the past five years. The behavior of individuals in situations involving problem solving, bargaining, learning the formation of coalitions and the performance of tasks under limited communication networks have all recently been subjects for experimental investigation.

There have been many economic theories concerning the behavior of two rivals in a bargaining situation or bilateral monopoly. The study of Siegel and Fouraker has begun to produce verification of some of the basic conjectures concerning the behavior of bargainers [45]. In particular they have studied the importance of knowledge of the other person's goals when bargaining. They observed that the lack of this information by either side had a profound effect on attempts to reach a "fair bargain."

Churchman and Ratoosh have experimented with a small group structured to simulate the organization of a firm [46]. In observing the behavior of the individuals engaged in jointly solving tasks set to the group they have found that in some instances even though one of the individuals is aware of the correct answer this may not be sufficient to have the group take action. This type of behavior matches the reasons often offered for the employment of consultants. It is claimed that in many hierarchies even though those of the firm may know the answers, it requires the presence of an outsider saying the same words to have them listened to and acted upon.

Several experiments involving two or more participants set in either an economic context or a more general bargaining situation have given results which indicate the value of the theories of behavior suggested by Nash, [46] and Lloyd Shapley [47]. Nash has presented a theory of non-cooperative behavior which is closely related to the behavior postulated by economists when there is no collusion present. Shapley's theory suggests that an individual can expect to obtain a reward which represents an average of his incremental worth to any coalition in which he could become a member. This theory appears to have relevance to political situations and other areas of human affairs where coalition structures are of considerable importance [48].

Business Gaming

Although war games have been used for many years by the military for purposes of training and analysis, only recently has there been a de-

velopment of their use as models of business situations. The American Management Association, IBM, General Electric, Pillsbury Mills, and many other corporations as well as UCLA, Carnegie Tech, and a host of other universities and business schools have constructed and are using these games.

They tend to be more complicated than the experimental games. The environment in which the play takes place is rich compared with the experimental games described above although, of course, it is not as complex as business itself.

The main use of these games has been for teaching and training purposes. They have been utilized for teaching at the functional level of a firm and for illustrating problems of organization, information and competition. The proponents of these games have often claimed that they are very useful in teaching an appreciation for the inter-relationship between different functions in an organization, and, in general, for giving individuals deeper insight into complex problems of interaction.

There appears to be little doubt that these games are useful teaching and training devices, although they may not be as effective as many of their proponents claim. Nevertheless, there is a complete area which to date has barely been exploited and which may well prove to be a very fruitful outcome of the interest in gaming; that is, the use of business games for experimental purposes. They have a great potential as a device by which much can be learned about decision-making.

The very rigorously designed experimental games used primarily by psychologists take place in an environment that is so simplified that

although behavior can be observed with experimental precision, many individuals would balk at making the inference that the observed behavior would provide a good predicting device for the behavior of decision-makers in a far more ccmplex environment. Business games provide an in-between stage in which to study behavior. Even though the situations tend to be far too complex for a thorough analysis, if care is taken before hand it is possible to design the game and have it played in such a manner that the data generated is of value in learning about the behavior of the players and in validating theories of behavior in relatively complex environments.

The business games in use at this time are restricted to numerical quantities. They are unable to cope with qualitative events. Although in some of these games a news or business letter may be circulated during the play in order to simulate qualitative effects.

In general, the larger games tend to utilize about twenty minutes to simulate the activity of business quarter. The players usually play between two to three years of a market history.

If the game is played with experienced personnel and is represented as a model of a business with which they are familiar it may easily serve as a device to aid the players in verbalizing their perceptions of their industry or market. Experience in operations research and management science indicates that in spite of hortatory writings there remains a vast preponderance of experience and know-how, which has been neither adequately recorded nor studied systematically. Business gaming now offers a new methodology to aid in doing this.

Simulation

The twin problems which beset those wishing to understand decision-making in the firm are first the observation and interpretation of behavior, and second the portrayal and analysis of the environment within which decisions are made. Most of the behavioral sciences do not have the means to perform controlled experiments. The development of experimental gaming and business gaming along with the advent of the high speed digital computer has helped to change this state in the study of areas of psychology, economics, and business. The advent of new statistical methods and the great increase in human ability to handle very complex models brought about by the computer has provided the possibility for the observation of complex economic systems in a manner that was impossible ten years ago. For those who wish to study various aspects of economic life, the advent of the computer together with study simulation and mass data processing techniques provides a viewing instrument that should have as profound an effect as did the microscope and telescope in other sciences.

A detailed discussion of the applications of simulation to the economy as a whole, to industries and the firm; and in the area of artificial intelligence is given in the December 1960 issue of The American Economic Review [49]. Some idea of their scope may be provided by observing that a large scale simulation of the demographic growth of the United States has been constructed. Simulations of the shoe and leather industries, the lumber industry, and several other industries as well as

detailed simulations of the workings of parts of a transportation system and sections of various firms have been built.

The sheer amount of discipline required in producing the flow diagrams and in checking for consistency between different segments of these large complex models in itself is of considerable value to the understanding of the nature of a firm, and industry or the economy itself. As a direct aid to decision-making in the firm, it is quite probable that within the next ten to fifteen years most large firms will be utilizing constantly up-dated simulators of themselves and their markets for planning and anticipatory purposes.

A simulator provides a means for testing out conjectures concerning the behavior of individuals en masse in a complex environment. As such, its use in the study of the overall economy, individual industries, and marketing and distribution systems promises to be great. As the work in gaming continues more and better theories of the individual will provide further inputs for simulations in an attempt to reach for the ultimate goal of understanding both behavior and environment together with their interaction.

VI. Conclusions

Necessity has forced the invention of a set of new words: decision theory, the behavioral sciences, information theory, the theory of organization, etc. The substance behind the names is nowhere near as great as we would wish it to be. However, it is growing in response to the needs of the times.

The traditional areas of economics, psychology, mathematics, and statistics to name a few, have not provided adequate theories of individual decision-making in a complex and uncertain environment. Having been forced to give up the model of rational man, the new work discussed here is beginning to replace him with a much less sure, more complex, and flexible individual whose problems and behavior are closer to those that we recognize in the world around us. The need to investigate the decision processes and the means by which to understand them have both mushroomed. A very different and much deeper understanding of decision processes is in the making.

How does this work influence universities, business schools, and the firm now; and how will it influence them in the near future? Management science and operations research have already had their effect. The more sophisticated uses of computers are constantly coming into being.

The new theories have already raised many new well-defined questions. The expanded possibilities of data processing and the growth of a scientific and empirical attitude in economics, government, business schools and management is resulting in a revolution in the gathering of statistics and the design of information processes.

Probably the greatest effect will come in the growth of experimentation and empirical investigation hand-in-hand with the growth of theory. Industry must be regarded and must regard itself in one sense as a vast experiment; with management itself as a subject for experimentation and observation. As the conjectures and hypotheses behind decision theory are confronted with demands for validation it will be increasingly necessary for researchers to understand, work with and design experiments with and on individuals and the institutions being observed.

Footnotes

1/ Sidney Alexander, "Economics and Business Planning," Economics and the Policy Maker, The Brookings Institution, Brookings Lectures, 1958-1959, Menasha, Wisconsin: The George Banta Co. Inc., November 1959.

2/ Herbert A. Simon, "Theories of Decision Making in Economics," American Economic Review, XLIX, June 1959, p. 253.

3/ Sidney Alexander, op. cit.

4/ Kenneth Boulding, Skills of the Economist, Cleveland: Howard Allen, Inc., 1958.

5/ Harold D. Laswell, The Decision Process, University of Maryland: Maryland, 1956.

6/ R. G. D. Allen, Mathematical Economics, London: Macmillan and Co., Ltd., 1956.

7/ A. Wald, Statistical Decision Functions, New York: John Wiley and Sons, Inc., 1950.

8/ R. D. Luce and H. Raiffa, Games and Decisions, New York: John Wiley and Sons, Inc., 1957.

9/ L. J. Savage, The Foundations of Statistics, New York: John Wiley and Sons, Inc., 1954.

10/ R. Eells, The Meaning of Modern Business, New York: Columbia, 1960.

11/ J. G. March and H. A. Simon, Organizations, New York: John Wiley and Sons, Inc., 1958.

12/ S. Siegel and L. Fouraker, Bargaining and Group Decision-Making: Experiments in Bilateral Monopoly, New York: Macmillan, 1960.

13/ R. R. Bush and F. Mosteller, Stochastic Models for Learning, New York: John Wiley and Sons, Inc., 1955.

14/ C. Shannon, "A Mathematical Theory of Communications," Bell System Technical Journal, 1948.

15/ M. Minsky, "Artificial Intelligence," (forthcoming) Proceedings of the IRE, January 1961.

16/ S. Siegel and L. L. Fouraker, op. cit.

17/ J. R. Jackson, "Learning from Experience in Business Decision Games," California Management Review, I:2, 1959.

18/ See "Symposium on Simulation," American Economic Review, December 1960.

19/ R. E. Machol and H. H. Goode, System Engineering: An Introduction to the Design of Large-Scale Systems, New York: McGraw-Hill, 1957.

20/ S. Gass, Linear Programming, New York: McGraw-Hill, 1958.

21/ G. B. Dantzig, "Linear Programming Under Uncertainty," Management Science, April-July 1955.

22/ Leonard Savage, op. cit.

23/ Ward Edwards, "The Theory of Decision Making," Psychology Bulletin, V. 51, September 1954.

24/ G. L. Shackle, Uncertainty in Economics and Other Reflections, Cambridge: Cambridge University Press, 1955.

25/ R. Bellman, Dynamic Programming, Princeton: Princeton University Press, 1957.

26/ J. von Neumann and O. Morgenstern, Theory of Games and Economic Behavior, Princeton, New Jersey: Princeton University Press, 3rd ed., 1953.

27/ M. Shubik, Strategy and Market Structure, New York: John Wiley and Sons, Inc., 1959, Ch. 10.

28/ P. Selznick, Leadership in Administration, New York: Row Peterson and Co., 1957.

29/ J. C. Abegglen, The Japanese Factory, Glencoe, Illinois: The Free Press, 1958.

30/ H. Simon, Models of Man, New York: John Wiley and Sons, Inc., 1957.

31/ C. I. Barnard, The Functions of the Executive, Cambridge: Harvard University Press, 1956.

32/ J. G. March and H. A. Simon, op. cit.

33/ C. Argyris, "The Individual and Organization; Some Problems of Mutual Adjustment," Administrative Science Quarterly, June 1957.

34/ Sun Tzu, "The Art of War," in Roots of Strategy, Brig. Gen. Thomas R. Phillips (ed.), Harrisburg, Pennsylvania: The Military Service Publishing Company.

35/ Ibn Khaldun, The Muquaddimah, (Translated by Franz Rosenthal), New York: Pantheon Press, 1958.

36/ J. Marschak and R. Radner, Economic Theory of Teams, Cowles Foundation Discussion Paper No. 59, 1958.

37/ R. R. Bush and W. Estes (eds.), Studies in Mathematical Learning Theory, Stanford: Stanford University Press, 1959.

38/ R. R. Bush and F. Mosteller, op. cit.

39/ S. Siegel, "Level of Aspiration and Decision-Making," Psychological Review, V. 64:4, 1957.

40/ C. Shannon, op. cit.

41/ G. Miller, "The Magic Number Seven, Plus or Minus Two," Psychological Review, V. 63:2, 1956.

42/ J. Marschak, Remarks on the Economics of Information, Cowles Foundation Discussion Paper No. 146, New Haven: 1960.

43/ J. McCarthy, "Measures of the Value of Information," Proceedings of the National Academy of Sciences, V. 42:9, September 1956.

44/ D. D. McCracken, "Machine Intelligence," Datamation, September-October 1960.

45/ S. Siegel and L. Fouraker, op. cit.

46/ C. West Churchman and Philburn Ratoosh, "Innovation in Group Behavior," Working Paper No. 10, Institute of Industrial Relations, University of California, Berkeley, January 1960.

47/ J. F. Nash, Jr., "Non-Cooperative Games," Annals of Mathematics, LIV, September 1951, pp. 286-295.

48/ L. S. Shapley, "A Value for n-Person Games," Contributions to the Theory of Games, V. II, Princeton, New Jersey: Princeton University Press, 1953.

49/ See footnote 18.