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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

INTRODUCTION

The lectures included in this volume represent some of the most recent material from the field of Operations Research theory and practice.

The Industrial Engineering Department, Industry Program of the College of Engineering, and the Extension Service of the University sponsored the series of fifteen seminar meetings during the 1956-57 academic year and the one-day symposium which was held on May 7, 1957.

Unless otherwise noted, the seminar lectures as presented here were written from notes taken at the time of each meeting. One of the symposium talks was transcribed from a tape recording made at the meeting; the remainder are manuscripts submitted by the speakers.

The primary purpose of this volume is to allow those who attended either the seminar course or the May 7 symposium to have a complete record of all the material. This is not a publication. No copies will be sold, and distribution is limited.

OPERATIONS RESEARCH

SEMINAR

1956-57

Mr. Salveson's complete manuscript has been made available for inclusion in this volume rather than the excerpts which were presented at the seminar meeting itself.

ENTREPRENEURSHIP AND OPERATIONS RESEARCH IN A LARGE DECENTRALIZED ORGANIZATION[1]

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Summary

Modern civilizations increasingly are dependent upon the uncommon creative individual in science, technology, and business for the maintenance and expansion of their levels of living. Many free peoples are tending to foresake their political freedoms, though, by relying upon socialistic enterprise to bring them the fruits of individual creativity in science and technology. Hence, there is an urgent need, if freedoms are to be preserved, to understand and foster those creative individuals in business who with a high sense of responsibility and purpose can perceive the need for and build the enterprises which supply our material needs, provide our employment opportunities, within the boundaries of free and private enterprise and, hence, maintain the economic conditions of political freedom. These individuals are the entrepreneurs, the builders of enterprises. The purpose in this article is to analyze the setting of the entrepreneur in modern, large, decentralized organizations, some of his psychological propensities, and the conditions favorable to his creative contributions.

The entrepreneurial process is analyzed and several important "conceptual-design" elements are shown to be rational and amenable to methods heretofore characteristic of the physical sciences. It is observed that the individuals who are moving into positions of entrepreneurial responsibility in extant organizations for the most part are salaried managers with little, if any, proprietary equity in the enterprise. They here are termed "entrepreneur-managers". Finally, a method and organizational instrumentality are demonstrated which can aid these entrepreneur-managers in pursuing their new role with greater effectiveness and productivity, and in "managing progress" more efficiently.

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1 The views expressed here are the writer's and do not necessarily reflect the official views of the General Electric Company, nor of any of its officers or managers.

"The greatest invention of the nineteenth century was the invention of the method of invention," according to Alfred North Whitehead (1).[2] It is believed the advent of the method of entrepreneurship during this same period was of equal importance; it provided both the means for making the invented goods and services available to the rapidly growing population and the basis of a vigorous industrial economy, based on a system of competitive, private enterprise.

It is asserted here, with rhetorical license, that the greatest invention of the first half of the twentieth century was the invention of the science of invention; that of the second half of this century will be the unfolding science of entrepreneurship. The development of the former "science" has been the result, in the main, of the increased power and efficiency of research and development methods in the physical sciences and of the increased understanding of the creative processes, such that it now is generally possible to devise orderly methods and programs for discovering and, or, applying new principles for achieving stated objectives. Through this development, society now is more able to invent systematically those goods, services and processes which it requires to sustain higher levels of living for enlarging populations. Our purpose here will be to explore some of the changes and circumstances which are leading to the second, closely related invention which now is unfolding: the entrepreneurial sciences. They are being developed perforce to find efficient methods by which the goods and services rapidly conceived by creative scientists can be made available quickly and on a broad economic basis. In this, we will attempt to analyze causal factors which (a) have changed important elements of entrepreneurship from a personal art to a task-oriented function; and (b) have provided the basis for raising some elements of that function from ad hoc opportunism and intuition to a profession which has accepted social, moral and ethical responsibilities, as well as firm foundations in certain concepts and methods of science.

Some of these factors are well known and widely recognized in industrial, economic and managerial circles. However, the central thesis to be developed here is predicated upon them as an axiom system. Hence, syllogistic considerations demand that they be reviewed as part of the exposition. In any case, the sequence in which these factors are presented does not represent an ordering of their relative importance to the problem at hand, but only convenience in presentation.

In some sets, the term "entrepreneur" may have, at present, an unfavorable connotation similar to "tycoon", etc. However, for the

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2 Numbers in parentheses designate references listed at end of article.

purposes here, the sense in which it is used is the basic functional meaning: one who builds an enterprise. The term "manager" is used in the basic sense as one who manages and who has a vicarious, custodial relationship to the object managed. Subsequently, the term "entrepreneur-manager" is introduced to describe the role of certain classes of managers.

I. Background and Assumptions

Increasingly large amounts of capital are being required in order to pursue research and innovation in industry. As the principles, concepts and relationships to be discovered and applied become more subtle, that is, as science becomes more advanced, the cost of carrying out the research seems to increase in geometric proportion. The consequence of increased cost of research and innovation is that only institutions or individuals with increasingly great financial, material and human resources can undertake them. Hence, the opportunity to innovate and, then, to build an enterprise on that innovation is confined in increasingly many fields to those who can marshall these greater resources. For example, Curtice[3] reported at the dedication ceremonies that the Research Laboratories of the General Motors Corporation needed for research and development cost $150,000,000.

Numerous examples can be cited to support this observation, atomic energy and electric computers, among many. In the first example, the role of Federal financing of the basic research is well known, and was beyond the abilities of any reasonable combinations of private corporations. But, even to develop the industrial applications of the previous results, requires, for example, joint endeavors of such large companies as Commonwealth Edison Company and the General Electric Company. In computers, it is common knowledge that the concepts and principles for development of computers originated with and were advanced by a variety of individuals with limited capital, such as Professors Eckert, Maucheley and Aiken. However, before their plans for research, development and application could be implemented, it was necessary for larger firms, such as Remington Rand, National Cash Register and others to buy their enterprises and to provide the necessary resources.

A closely related phenomenon is the increased resource requirements for initiating the production and distribution of many goods and services. No elaboration is necessary for full appreciation of the

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3 President, General Motors Corporation.

amount of resources which the entrepreneur must command before he can build an efficient, large-scale enterprise. Even though roughly 1000 new enterprises are formed each day in the United States, the majority of these are in commerce and trade, and less than one-fifth of them survive more than five years. Inadequate financial resources are reported to be the preponderant reasons for their failure.

In a modern civilization industry and commerce in one perspective may be considered the locus of the application of all of man's arts, skills, energy and knowledge as he wrests a living from nature. Thus, the enormous proliferation of scientific and technical knowledge and of business information introduces another factor complicating the process of entrepreneurship. For example, the success of a particular business venture may depend upon such diverse knowledge and abilities as understanding consumer motivations, metallurgy, organic chemistry, multi-variate statistical analyses, as well as the ability to integrate and coordinate these different fields into an organized and functioning enterprise. The fact that it is becoming less feasible for one person, or even small groups of persons, to master these diverse disciplines reduces the chances of successful innovation and entrepreneurship by other than groups with considerable human resources. Thus, the complexity of business operations and the corresponding need for functional specialization in meeting this complexity, impose a lower limit on the size of the group that can be successful in building a new enterprise.

The development of the scientific method itself in its full detail, complexity and application introduces a further element which mitigates against the "buccaneer" type of individual entrepreneurship. While the entrepreneur, considered as a group or as a function, must have the traditional boldness and audacity, these qualities alone are becoming increasingly insufficient as a basis for building an enterprise. They must be supplemented by skill in scientific methods of analysis and of theory building and problem solving. This skill is in addition to the functional specializations, since an enterprise may call upon many diverse fields of knowledge; often, the only common thread during the early stages of the development may be a scientific perspective in approaching the situation and determining the basic theory of the enterprise. Again, the development and marshalling of such diverse talents and qualities often require large-scale resources.

A less obvious factor affecting the nature of entrepreneurship is that the opportunity for enterprise itself is changing rapidly. That is, the unique combination of need, process capabilities, and resource availability -- out of which the opportunity to create an enterprise arises -- may be so technical and so related to technical factors that it might be seen only by persons who normally would not be aggressive and venturesome. For example, an engineer or scientist, through his technical work, may discern the possibility of producing goods via some new production process. The unique combination of need, process and good would be visible only to a person with his level of competence and familiarity with these three elements of the entrepreneurial situation. Nonetheless, because such persons are prone not to be "audacious and bold", and do not take the risks involved in building an enterprise, they often merely pass the opportunity along to others, or allow it to slip away.

Although the opportunity for entrepreneurship frequently arises out of purely technical innovation (there are other sources, of course), there is a serious difficulty to the entrepreneur from the current high "rate" of technical innovation. For example, one of the typical difficulties in the electronic computer field has been the rate at which new innovations have obsoleted earlier ones. This short life span leads to problems on timing the introduction of innovations, financing and writing off previous development costs, balancing between the "ultimate" in the product and currently feasible designs, etc. When one considers the full spectrum of research, development and application as a source of invention and innovation, it is obvious that there are serious entrepreneurial problems involved in "managing progress" (that is, in the analysis, the acceptance, the incorporation and the timing of innovation in an enterprise) which require intensive study for their solution and handling.

For example, Maclaurin (2) cites Owen D. Young: "Fifteen years is about the average period of probation, and during that time the inventor, the promotor and the investor, who see a great future for the invention, generally lose their shirts. Public demand, even for a great invention, is always slow in developing. That is why the wise capitalist keeps out of exploiting new inventions." On the other hand, Schumpeter (3) frequently emphasized that the most profitable industries are those in which there is a high rate of invention and innovation. Thus, there are fine problems of balance for the entrepreneur in timing the introduction and analyzing the application of innovation in order that progress, based thereon, may be rapid, orderly and efficient.

The preceding factors tend to give the large organization important entrepreneurial advantages, as well as a large social responsibility for effective entrepreneurship. On the other hand, there are factors which may tend to operate in favor of the small organization or individual as an efficient entrepreneurial agent. Some of these follow:

Newcomer (4) emphasizes numerically the magnitude of the change which is taking place in the background and route via which the presidents or chief executives of modern large corporations gained their position in 1900 as compared to those in 1925 and in 1950. One of her findings is reproduced here; note the shifts particularly in the increase in engineers and managers into the primacy in this sample of corporations.

PRINCIPAL OCCUPATIONAL EXPERIENCE OF (CHIEF) EXECUTIVES

	Number of Executives			Percentage of Executives		
Occupation	1900	1925	1950	1900	1925	1950
Entrepreneur[4]	97	66	86	31.0	20.2	9.9
Capitalist	39	20	43	12.5	6.1	4.9
Banker or broker	24	12	43	7.7	3.7	4.9
Engineer	39	51	168	12.5	15.6	19.3
Lawyer	41	45	104	13.1	13.8	11.9
Other Professions	12	9	69	3.8	2.7	7.9
Salaried Administrators	61	123	358	19.5	37.7	41.1
Total	313	326	871	100.00	100.00	100.00
No Information	3	4	11			

From Newcomer's tabulations, it is obvious that entrepreneurs (in her sense as those who themselves conceive, establish and operate independent business enterprises) have declined to less than one-third of the earliest percentage. Capitalists have experience a marked decrease. There are many reasons cited for the preceding changes. Among these is the simple fact that between 1875 and 1900 there was a very high rate of formation of corporations, many of which continue through

[4] "Entrepreneur" is used by Newcomer to indicate individuals who originated an enterprise, a concept which does not include the "Entrepreneur-Manager".

to the current period. The span from 1900 to 1950 is so great that few of the original entrepreneurs remain as incumbent chief executives. They must have been replaced by others. Newcomer observes that those chosen tend for the greatest part to be those salaried administrators or engineers who, at the time the replacement is made, are on the scene, are available and are familiar with the business.

Of course, every extant enterprise has both an origin and an originator(s). Thus, the decline in chief executives who originate businesses, even businesses different from those they now are managing, to nine percent of the total is even more striking. Without anticipating certain subsequent remarks, the entrepreneur's contributions include conceiving the opportunity for enterprise, marshalling resources to the enterprise, accepting the risks of the enterprise and creating the image or design of the enterprise as a unifying activating concept for other members of the enterprise. These contributions require certain personal qualities, including a high degree of creativeness and considerable boldness. By definition creativity is breaking with an established order so as to bring a new level of understanding or order to human experience. Boldness is required to apply results of the creative entrepreneurial processes to the building of an enterprise.

Successful entrepreneurship (either by an individual or a group) requires both qualities: boldness and creativeness. However, unless considerable care is taken in the selection of personnel for positions of entrepreneurial (or top managerial) responsibility, persons with this combination of qualities easily might be "deselected" in the large, stable enterprise which otherwise have the required resources. For example, Torrance (5) reports findings which tend to indicate that bold, adaptive military officers, the analogues of the creative industrial entrepreneurs, often do not fare so well in stable, established organizations, so that if the entrepreneurial function is to be performed well, care must be taken to assure that they are not so deselected. Their creativeness to break with tradition in order to achieve progress and boldness to pursue the break may be interpreted as disagreement, especially as person-oriented disagreement. Torrance writes:

> First, management needs to accept the fact that task-oriented disagreement is almost always "good". You have been long conditioned to believe that it is "bad". Parents become quite disturbed if their children argue or fight. Teachers, managers and supervisors behave similarly. You may be afraid that you are "playing with fire". "What if somebody blows up? What will the higher-ups think? Will I lose the respect

of my subordinates by letting them disagree with me?" Perhaps, you are neglecting to recognize the fundamental difference between task-oriented and person-oriented disagreement. Or, you may be too prone to assume that all differences of opinion are a threat to managerial control.

I think one extremely valuable application for management comes from the findings concerning individual performance and willingness to oppose others. Willingness to disagree is a major characteristic of the aces -- the high achievers. It also characterizes those best able to meet frustration, those most willing to take calculated risks, and those who have the most "will to fight". In spite of the fact that most really outstanding people appear to have this characteristic, many of them fare rather badly at the hands of management, both in business and in military situations. They are seen as threats by superiors and are frequently not tolerated. Too often the greatest rewards are for conformity.

Another factor affecting entrepreneurship inheres in the organizational structure of the large enterprise. As the size of an enterprise increases, the organization and communication structure tends to become more complex. There may be an increase in number and variety of communications channels, a proliferation of necessary functionaries, greater need for and extent of specialization of managerial and professional work, a tendency in many instances for specialists to identify themselves with their speciality or profession more strongly than with the enterprise in which they practice their professions, a tendency for specialties or professions to develop their own vocabularies and thus increase the difficulty of integrating them into the enterprise. Together, these tend to reduce the sensitivity of the organization to its environment, to hamper its speed and flexibility of response to environmental stimuli and to opportunity inherent in innovation, and thus to inhibit its ability to function as an efficient entrepreneurial agent.

Thus, it should be clear from the preceding that the large organization is confronted with conflicting tendencies in its ability to perform the entrepreneurial functions. One current avenue for seeking the advantages of the large organization's resources and the small organization's flexibility and simplicity is to "decentralize" the business and operations of the larger enterprise. In particular, we cite Cordiner's[5] (6) plan for decentralizing the operation and

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5 President, General Electric Company.

management of the General Electric Company. One of the implied purposes in this plan is to permit the Managers of the various Operating Departments of the Company to continue to perform efficiently as entrepreneurs and, thereby, to make those contributions to the public, the customers, the employees and the shareowners which derive uniquely from the resources of a large private enterprise. Through this adaptation, it is believed it will be possible to cement more firmly the free enterprise character of the American economy by quickly and productively satisfying the needs of society, by providing opportunity for gainful employment and investment, and by doing these in a manner consistent with the maintenance of competition and of individual liberties and initiative.

The effect of the plan has been to establish approximately one hundred highly autonomous businesses within the General Electric Company, each producing a related or homogeneous set of products or services. Each such business is managed by a General Manager and staff of Functional Managers, such as Marketing, Engineering, Manufacturing, etc. In many regards, the General Manager and Functional Managers are equivalent, respectively, to the Presidents and Functional Vice Presidents of smaller, independent corporations with sales ranging from 5 to 500 million dollars per year. The scope and scale of these decentralized businesses are designed to be not greater than what "a good manager can get his arms around" (6) (The operational meaning of this definition is intuitively clear to most readers.) By so proportioning these businesses, some of the difficulties of performing the entrepreneurial functions are largely overcome, including designing the enterprise to be sensitive, and responsive to stimuli from the market, from the competitors and from the economy, to have greater ability to innovate and to manage progress more efficiently.

This concept of decentralization has given the Managers of these businesses a new dimension of responsibility: they now are responsible for both the traditional custodial-type managerial activities ordinarily associated with operating an enterprise, as well as the entrepreneurial activities associated with initiating, modifying, and "growing" an enterprise.

Certain entrepreneurial activities and functions are reserved, of course, to the President and his Executive Office. Of particular interest here, is that the selection of General Managers of these businesses is reserved to the President's or a Divisional Vice President's Office. In view of the nature of the Company, therefore, it could be stated that one of the recent primary entrepreneurial contributions of the President has been to redesign the enterprise so that he and his principal delegants manage a large group of Entrepreneur-Managers, each of whom is responsible for one highly autonomous enterprise. In view of the increasing complexity of industry, this pattern of decentralization could prove to be a highly important device in developing the entrepreneurial-managerial talent in the quantity and quality necessary to maintain an efficient, productive industrial economy.

Some of the other powers reserved to the President's Office include the determination of the basic kinds of businesses in which the Company will engage, planning adaptations and innovations to meet broad, fundamental societal and legal changes, public representation of the Company, etc. These functions have been generated by society's new level of awareness of the role and behavior of each of its segments. They have been stimulated equally by a new level of social responsibility now accepted by business leaders.

Thus, leadership in innovation and adaptation in the broad socio-economic areas increasingly comprise the entrepreneurial task of the chief executive of the large organizations.

One consequence of true decentralization of an enterprise, which is of particular interest here, is the new stature gained by its chief executive and the managers of each of its constituent enterprises. That is, the autonomous entrepreneur is usually chief executive of his enterprise and typically bears the entrepreneurial responsibility and authority within that enterprise. He hires and supervises managers to whom he typically delegates "operating" responsibility. The primary measure and evaluation of his entrepreneurial performance are through undiluted economic criteria: the immediate, rather than the long term, usefulness, contribution, and efficiency of the enterprise.

In the context of true decentralization, the chief executive delegates much of his authority and responsibility as entrepreneur to the principal managers of each of the constituent enterprises. By this delegation they become "entrepreneur-managers". This delegation, however, leaves a residual of the authority and responsibility with the chief executive to measure and evaluate the performance of his delegants. The measurement and evaluation methods applicable in this regard are not at all obvious. Current profit alone is not adequate as such measure. For example, new enterprises often experience losses, regardless of their social or economic desirability, during their early years. Technological or social change unexpectedly may change the basis of an enterprise and cause it to be unprofitable during a readjustment period. An inept or poorly motivated entrepreneur-manager may "bleed" a constituent enterprise in order to gain immediate profits, or otherwise leave it in a disheveled state so that it will remain unprofitable during a rebuilding period. There are, of course, many other causes of temporary unprofitability, so that other criteria and measures must be devised. In any case, this requirement of measuring, evaluating, and supervising the delegant entrepreneur-managers in turn requires a level of understanding of the role, function methods, and characteristics of the entrepreneur not formerly known or available. This applies equally to our understanding in relation to embryonic, growing, as well as mature enterprises.

This new level of understanding of the entrepreneurial function, as well as the ability to use that understanding, provide powerful aids in achieving the objectives of the enterprise and its constituents, as well as of the society of which it is an integral part. It is this new ability which raises the stature of both the chief executive, as well as the delegant entrepreneur-managers to a new height. Both the chief executive and the entrepreneur-managers can plan growth and development of the various constituent enterprises in such manner as to achieve greater productivity, and profitability and stability. Each can achieve these as follows:

1. The chief executive, as a high level industrial statesman can recognize or anticipate poor entrepreneurial performance in any relevant process or function of enterprise before unprofitable or undesirable conditions develop; thus economic efficiency, profitability and social utility are all enhanced. Also, he can multiply his own personal skills and insights through his teaching and coaching of the entrepreneur-managers. He can bring his skills and unique insights to bear -- unfettered by diurnal operating responsibilities -- on broader, more fundamental issues, for example, those concerned with maintaining political conditions favorable to individual freedom and social progress.

2. The delegant entrepreneur-manager can make a greater contribution, also. His enterprise can be built on firmer long-term trends and relationships, less on the shaky sands of transient economic vissicitudes. This contributes to stability and growth of both the enterprise and the economy. He, thus, can derive a greater sense of satisfaction from his semi-autonomous, but more responsible,work.

At first blush, it may appear that the foregoing are ambitious claims to make. It is submitted, however, that they are not out of proportion with reality. That is, modern physics and engineering with all of their material benefits to society derived from better understanding of physical phenomena, starting with Galileo and Newton. It is suggested here only that corresponding benefits can accrue from better understanding of the economic and psychological phenomena of entrepreneurship. The opportunity for this understanding derives or is stimulated by the recent concept and practice of decentralization, and by the delegation and measurement of the entrepreneurial functions.

The current trend to decentralization provides an excellent opportunity for scientists of entrepreneurship and of management to study, under realistic conditions, the functions and contributions of entrepreneur-managers, such as those who now manage either autonomous or constituent enterprises. This analysis is based on such a continuing study, with particular reference to the entrepreneurial functions, as well as to the methods and instrumentalities by which they are or can be discharged in constituent enterprises. It is concerned particularly with certain concepts which become apparent through the insight gained from the experience of this decentralization and its attendant alteration in the role and relationship of entrepreneur and manager.

II. Analysis of Planning

The entrepreneurial functions are examined more closely through an example which, while simplified, nonetheless contains the essential elements of management and entrepreneurship in more realistic situations. In particular, it underscores some functions in business planning and research in order that the relationship between management and entrepreneurship may be presented later in the article. Analysis of this relationship was stimulated by the cogent question, asked by a vice-president of a large decentralized organization, "Our greatest need in improving as managers is: what to do before we begin to plan?" The example is constructed by analyzing and extending a brief illustration of the planning process which appears in (7):

> Planning is necessary if chosen goals are to be reached, as will be illustrated by a simple analogy with automobile travel. The importance of planning is greater, the longer the journey, the greater the need for haste or directness, the more diverse the choices among many possible vehicles and roads, the more people involved in the adventure. An aimless Sunday afternoon drive, just for the fun of riding, requires little advance planning except to have the car in good mechanical shape, the gas tank full and the occupants ready at an appointed time and place. On the other hand, those who plan a transcontinental or foreign trip, but are limited in time available,

and have decided preferences as to places to be visited, will plan routes carefully, make advance reservations and will spend considerable effort to be sure that their plans are complete, so as to reap maximum benefit from the journey when it is taken.

Upon analysis, it is discerned that this traveler, or planner, has at least the following:

1. An objective he wishes to accomplish as best he can, e.g., "to reap maximum benefit from the journey";

2. A meaningful preference scale or measure on his objective, e.g., "decided preferences as to places to visit";

3. A limitation(s) on his resources, e.g., "he has limited time available".

In order to achieve his objectives in some optimal manner, he will:

1. "Plan routes carefully" (the method or process of planning).

2. "Be sure plans are complete" (test results of the process).

3. "Make reservations" (initiate action on plan).

Consider the process in more detail by one possible specific instance, a trip in which the traveler wishes simply to visit all the state capitals and return to his point of departure via the shortest route. There are exactly 48! (48 x 47 x 46 x . . . . x 2 x 1), or, roughly, at least 10^{50} different routes. From among these the traveler must select only the shortest route. Even though the traveler might enumerate 1,000,000 routes per second, there would not be enough time from the instant of creation until the stars are extinguished to enumerate them all. Yet, traveling salesmen do plan such trips, and some recent "operations research" studies have been concerned with solving problems of this type. In particular, Dantzig, et al., (8) have developed an algorithm or method, which, while heuristic in some regards, has found one shortest route for this problem and proved it to be so.

Of course, there are other planning situations, for example, in manufacturing, marketing, etc., and there are other quantitative and qualitative planning methods. A full survey and description of these methods would be immensely valuable to managers who must use, or select persons who can use, them as required. Such a survey is not now conveniently available in the literature on planning, but is beyond the scope of this paper.

The second feature of the travel-planning example to note is that planning the route required the existence (in this case) of two information-containing documents: a road map and a mileage chart. The documents are independent of the planner or any planning which he may perform. Instead, they are generally available knowledge or information generated through research or measurement. Often, in the technical literature on planning, these may be termed "structural data".

These basic data are essential to the planning process. It would be virtually impossible to plan a trip, as in the traveling-salesman problem, or any other operation, if the data were not available or if they had to be determined during the planning process, as their need became known. The purpose of citing here the distinct difference between the planning process and the planning data is to emphasize the need for determining what data should be researched before the managerial planning process can begin. At this juncture, it is possible to discern at least the following classes of data and functions of planning:

a) Structural data on the elements and operations of the system within which a plan is to be developed;

b) Structural data on amount of each required resources available;

c) Method and criteria for testing plans as to feasibility, consistency and completeness;

d) Method for generating, and

e) Criteria for selecting best or set of best plans according to how well it accomplishes the objective which is to be sought by the action being planned;

f) A value scale or measure for evaluating or for comparing the diverse accomplishments of a plan and, hence, for providing the value characteristics for the criteria in (e) above.

Other classes of data are required, as is obvious, when the tentative character of all knowledge is considered. For example, the traveling salesman impliedly accepted as "absolute" the distances, road conditions, and travel times between capitals. Actually, these can be quite variable or uncertain. Thus, our information is never perfect nor complete. The planner, if he is rational, therefore, should know:

g) The probable increment of cost or inconvenience associated with each event that would disrupt or interfere with the objective, that is, its "negative value";

h) Probability, or estimate of probability, of occurrence of events which disrupt the attainment of the objective;

i) Cost and probability of obtaining "better" information on whether such descriptive event has or will occur.

With these additional data the planner rationally then can plan his trip or operations, as well as his expenditures for emergencies, such as, in this example, membership in an automobile club.

Of these classes of information only class (d) is properly called "planning". The others are kinds of information which must be brought to the planning process.

In the general business situation, it is important to note that the research or measurement to generate these data must precede the planning process itself. For example, suppose the traveler decides to use a travel agency; let us examine the processes which precede and ensue their discussions. On the one hand, the traveler will bring, consciously or unconsciously, to the discussions his preferences in places to visit, in modes of travel, in sequence and timing of visits, plus his resource limitations in time, money and energy. On the other hand, the agency, if it is to serve its purpose most efficiently, will have information on modes of travel between locales, fares, timetables and estimates of reliability thereof, comfort, convenience and rates of accommodations, points of interest, rates of exchange, etc. These data will have been deliberately researched and maintained current, without expectation that our specific traveler would use the service, but in anticipation that persons with his interests would use it.

The trip-planning process with the travel agency then involves iteration or statement of possible itineraries, test of feasibility and evaluation of relative goodness. The process is efficient if there is an efficient planning algorithm and if the preference and structural data are complete, systematic, and in usable accessible form. For example, if the traveler inquired as to the possibility of a side trip to Rheims, the agency should have pertinent structural data on fares, as well as information on whether the Cathedral was destroyed. If the agent had to phone or wire for such information, the planning process would be impossibly delayed. Thus, we easily can see that research must precede these planning and decision-making processes.

III. Analysis of Entrepreneurship

It could have happened that some historically early traveler conducted the research necessary to plan a major trip. After completing the preparatory research, after experiencing the difficulty of planning the trip, and after taking the trip, he could have recognized that gathering, codifying, systematizing and maintaining current files of travel information were arduous tasks, but that they provided extremely vital information to planning and taking an enjoyable tour. Thus, he might have concluded that this function, i.e., research and planning assistance to prospective travelers might make the basis of a profitable, socially useful enterprise. If he proceeds to develop this enterprise, he becomes an "entrepreneur". He conceives the basis of and originates an enterprise to fulfill an economic need which he has discerned. He determines the scope or extent of its activities. He determines and commits resources to bring it to fruition and initiates the actions necessary to activate it. He may or may not "manage" it once it is in operation.

There is a whole class of questions which he must answer if his new enterprise is to be "successful", at least in the sense of being able in the long run to command more resources to it than it consumes in process of its operation. He will have to decide that there exists or that there does not exist an "opportunity for enterprise" in the conditions which he experienced. In order to make this decision, he will want to know much about the market for his service, the prices he can charge, the demand for his service, the category of demand, as well as the cost of researching and maintaining the information on which his services would be based. He will want to estimate the probable number, timing, composition of travelers who might use his services, as well as the variety and kind of trips, durations, amounts of expenditures, etc. From these, he can make entrepreneurial decisions on the kind and scope of the enterprise he is to establish. For example, is it to be the "Brooks Brothers" of travel agencies, or the "Robert Hall"? Obviously, this basic entrepreneurial decision on the kind of enterprise makes an important difference governing such derived managerial decisions as location and decor of the sales offices, the information which should be researched and maintained (e.g., whether on tramp steamers and hostelries or on first class ships and hotels), level of sophistication in advertising, credit and collection policies, amount of cash reserve required, adjustments to seasonality of business, etc.

The entrepreneurial interest and responsibility do not terminate with the initial selection of scope of enterprise. Rather, they continue actively in such questions as: should the enterprise grow or contract; in what direction and at what rate should it grow or contract; what services should be added or deleted; what new markets should be tapped; what level of risk should be taken in capital investment; what adjustments should be made to any environmental and societal changes in the opportunity for enterprise? Thus, the entrepreneur's decisions profoundly affect the scope, nature and profitability of his enterprise throughout its life or his.

To demonstrate further the function of the entrepreneur, it is easy to recall many entrepreneurs who founded enterprises and who may or may not have managed their enterprises once they had been founded. They made important industrial and social contributions through their entrepreneurial actions. Two notable ones in the electrical manufacturing field were Edison and Westinghouse. Of Edison's contribution, Passer (9) writes:

> "The process of development of electrical manufacturing may be taken as representative of a pattern which has been repeated again and again as new industries, founded on new technologies, have come to be important in the economy.
>
> A key person in this process is the engineer-entrepreneur, the person with technical training who can see commercial possibilities in the application of scientific principles and who labors to perfect usable products and techniques. This kind of entrepreneurship has become increasingly important as the advance of science has made available new knowledge, new products, new production methods and new resources. For, the the long view, the most significant manner in which to increase economic welfare is not through better administration of existing resources or change in the distribution of income, but through applications of science which increase national income. . . .

> Because Edison was profit oriented, not in spite of it, he fostered economic development, increased the national income, and raised the standard of living of the mass of the people. If he had been motivated by broadly humanitarian ideas --- and, possibly, he was --- he could have hardly acted more effectively than he did. . . .
>
> How the pattern of Edison's activities in electric lighting was influenced by profit consideration can be briefly outlined. He chose lighting over other possible areas . . . because he felt that there were bigger rewards in lighting . . . His goal was to produce light at the lowest possible cost . . . He invented the high resistance filament because he realized, first, that it was necessary to economic lighting . . . His dynamo differed from those that preceded it in its high efficiency . . . Edison's contribution to the transmission network was to invent a cost-reducing component."

When Westinghouse was elected to the Hall of Fame, the following appeared in Mechanical Engineering (10):

> George Westinghouse, ASME President in 1910, engineer, inventor, scientist, and humanitarian was elected to the Hall of Fame for Great Americans. He is credited with almost single-handed responsibility for adoption of the alternating current system which proved the key to the electrical era as we know it. His air brake and friction draft gear made possible safe, swift rail transportation. He first adapted the geared steam turbine to the job of driving ships. The George Westinghouse bust which has been on display at ASME headquarters will be placed in the Hall of Fame for Great Americans. His associates conceded that Westinghouse defied classification; they compromised by naming him the "World's Greatest Living Engineer". His inventive talent produced 361 patents. His business proficiency made possible the organization of 60 companies worth more than $200 million at the time of his death in 1914.

Similar stores could be written for other well-known entrepreneurs: Vanderbilt, Carnegie, Ford, Sloan, Coffin, Rockefeller, Robert Brookings, Marshall Field, etc. Their proficiency was, in the main, not in managing, but in being enterprising and in performing various of the entrepreneurial functions. For example, if Westinghouse had confined himself to "managing" the first enterprise he created, it is quite improbable that the other 59 would have come into existence. He could not have been an active manager and still be as productive as he was as an engineer-entrepreneur. Indeed, he is a good example of an entrepreneur whose work was virtually undiluted with managerial work.

If the functions and contributions of the entrepreneur in the preceding paragraphs are analyzed, it is discovered that he performs the following functions:

1) He discovers, conceives, or creates the opportunity for enterprise, whether that opportunity is due to a technical or scientific innovation or invention, a social or political change, or other;

2) He defines or states a consistent, meaningful theory of the enterprise, albiet intuitively or unconsciously, which outlines his central beliefs as: what the opportunity is and what must be done by the enterprise in order that it may be seized;

3) Based on his theory, he designs the enterprise, as to scale, scope, organization, etc. which is manageable and which is capable of seizing the opportunity for enterprise;

4) He synthesizes and portrays a clear picture of the design of the enterprise, through governing objectives, policies, goals, planning criteria, etc., thus providing the integrating concepts for the diverse functional components of the enterprise;

5) He evaluates the risk and reward inherent in entrepreneurial decision and accepts or rejects; he evaluates, marshalls and commits required resources to the enterprise;

6) He motivates and activates the enterprise into existence and operation at the selected propitious time;

7) He revises his theory, design, scale and scope of enterprise for growth, contraction, or change in direction as appropriate with the passage of time and with change in the total environment.

In order to fix ideas, consider the following alternative example in which the actions and contributions of an entrepreneur are analyzed into these categories. Take, for this example, an entrepreneur who creates an apartment enterprise:

1) To discover or conceive the opportunity: through his knowledge of, or research on population growth, migration, personal living tastes, employment opportunities, or any combination of these or other factors, the entrepreneur discerns the need for housing in a particular locale at a particular time. The need may be active, or it may be latent, and require education, advertising, or other to make it active.

2) Define theory of the enterprise: from his knowledge of the various types of housing which could be constructed, his insight (however obtained) into the modes of living preferred by those who need the housing, their ability to pay prices or rents, etc., he constructs a theory on how the housing need could be met. This theory, consciously or unconsciously formulated, contains such propositions as "the expected tenants have few, if any, children; their occupational status permits them little time for garden culture and domestic chores; they typically prefer 'to be close in' to shopping and other commercial areas, etc.; single-family dwelling units typically are preferred by heads of growing families, apartment-type dwellings are necessary to justify the high cost of land in the preferred location, etc.; thus, an apartment of a specified capacity appears to be indicated." A particular advantage in recognizing that there does exist a "theory" for each enterprise is that the whole structure of the theory can be developed formally, including the assumptions, propositions, and logical reasoning. These can be tested formally, of course, for their validity, completeness, and consistency. Often, indeed, great value derives simply from these preliminary tests.

3) Design the enterprise: like all theories, whether physical, social, philosophical, or other, the entrepreneur's theory requires "reduction to practice" via a specific design before it can be implemented or made to serve as the basis for action. In this case, the design of the enterprise contains obvious tangible design features as well as less obvious conceptual features. However, the tangible derives from the conceptual. That is, the entrepreneur initially must construct a "model" or models (in

the engineer's or econometrician's use of the word) or image (in the artist's words) of the enterprise. This model offers a comprehensive representation of how the apartment enterprise probably would operate under the different designs, including possible combinations of rents, locations, decor, landscaping, building services, lease conditions and terms, size and number of rooms, personal services (doorman, hotel service, maid service), etc. Some of the entrepreneurial decisions in the optimal design of the enterprise will be incorporated in the architectural and structural design of the building; others will serve as governing decisions on policies, attitudes, etc. of the intangible aspects of the enterprise.

4) Synthesize and portray the design: there is a large difference between creating a design and portraying that design. For example, to the design engineer a wholly adequate design of a structural beam may be an equation or formula on his work sheets. But, to portray the design to others will require blue prints, material specifications, etc. Similarly, our entrepreneur here must portray his design by suitable architectural drawings and specifications, instructions to the apartment manager, selection of advertising message and content, etc. These portrayals permit participants in the enterprise --- the architect, the manager, the tenants, the gardener, etc. -- each to visualize the enterprise in such a way as to determine and guide his role, therein, so that his contribution to and reward from may be consistent and mutually acceptable. They also permit the entrepreneur to analyze and determine the extent to which the design is consistent and complete.

5) Evaluate risk and reward and marshall and commit resources: in as much as life is characterized more by uncertainty than certainty, there will be some risk that the enterprise will require more resources than it can command and, hence, will fail. The entrepreneur must weigh the probability of various magnitudes of rewards and decide, by some process, that he will proceed with the enterprise. Then, he will marshall and commit the required resources to it, including his time and capital, borrowed capital, hired labor, etc.

6) Activate the enterprise: one of his key acts in building the enterprise will be to retain his architect, his building contractor, and his apartment manager. Through this process he activates the design and erection of the building and the commencement of the business of operating the apartments.

7) Revise the enterprise: unless he is omniscient, there will be changes in needs, in circumstances, in population characteristics and movements, in prices and rents, which will affect the assumption underlying his initial theory of his apartment enterprise and which, in turn, will indicate changes in design of the enterprise in order to adjust optimally to the new situation. The entrepreneur must repeat in whole or in part the entrepreneurial processes in order to achieve this adjustment. He cannot allow his manager to manage the enterprise into extinction by his own failure to continue to adjust the enterprise to changing circumstances.

IV. Analysis of the Entrepreneurial Personality

There are relatively few entrepreneurs in the active sense of the word. Similarly, few persons are "pure" (unadulterated) entrepreneurs and do no other kind of work. But, some are more inclined to be entrepreneurs than others. Our interest at this point is stimulated by the enormous importance of the entrepreneur as a factor in economic and industrial growth, in satisfying economic needs, and in advancing economic material and, inescapably, social well-being. Hence, attention turns now to the kind of person(s) who successfully performs the entrepreneurial functions. Society, corporations, etc. should be interested in recognizing him, in creating efficient conditions for him, and in understanding him. His critics and friends need to recognize his contribution and function. Randall (11) notes that the entrepreneur may be forgotten even in the enterprises he has established:

> On the other hand, there are many executives running successful companies by today's standards who, individually, never pause to examine the histories of their companies. If they did, they would find that, in the main, their present status was owing to a few bold, inventive, creative people who, by accident, persistence or sympathetic handling built the foundation of the other's present successes.

On analysis of the preceding examples of entrepreneurs in action, it can be seen that each must be highly endowed with certain qualities. He must be:

1. Perceptive

2. Creative

3. Active or aggressive

In addition, he must have a particular

4. Perspective

toward affairs of the world, including specialized kinds of work.

His perceptiveness is necessary in order that he may "see" in his environment certain needs, new abilities, changes in habits or patterns, etc. out of which he derives his fuel for his creativity. Often, this perceptivity must be limited to a relatively narrow field. For example, different sets of background and training would be necessary in order to perceive the opportunity for enterprise in the need or usefulness of a travel agency, in the existence of classes of unsolved problems in engineering and science, together with the problem-solving ability of electronic computers, etc. In broadest terms, his perceptiveness reflects the fact that he is more sensitive to his environment and derives more useful information from it than others do, because of his better training, experience or innate ability.

His perceptiveness provides the fuel for a more important attribute, his creativeness. He has the ability, technically and conceptually, to conceive new combinations or patterns so that he may fill a need, seize an opportunity, or solve a problem. In the modern, complex economy, the creativeness required to conceive the theory of and to design a new socially-useful enterprise, may be as great and as sophisticated as that required to conceive, say, new physical, mathematical or "scientific" theory, especially when a high sense of social responsibility strictly limits the extent to which the laissez faire philosophy governs the entrepreneurs.

The entrepreneur differs from other theory builders; he does not stop with creating the theory and developing the design based on it. He must take the initiative and motivate action necessary to reduce the theory and design to practice. He "does something about" his discoveries and creations. He does not stop, say, when he has developed a new theorem, as the mathematician may, but he labors onward to build an enterprise on that theorem. For example, as early as 1802, Davy, a scientist, experimented with electrically induced incandescent lamps. But, he only noted in his log book that "the rod glowed until consumed". On the other hand, Edison, an entrepreneur, labored to develop, not only a rod that would not be consumed, but also, raised money for his experiments, saw a need that could be served by the invention, and labored to invent or improve other devices, such as dynamos and transmission networks, so that he could "do something about" the commercial application of incandescent lighting.

The perspective of the entrepreneur, also, is different and unique; to him, the irreducible unit is the enterprise. He must conceive of the activities of himself and the other participants as parts integrated in and contributing to that whole. He does not "do engineering" or think of engineering except as one activity and specialized contribution required by the whole of the enterprise in order to achieve the enterprise's purpose. Similarly, he does not do accounting for the sake of keeping accounts, or because he is a professional accountant, but, rather, to aid him in preserving the assets and resources of the enterprise.

The entrepreneur's interest in such components of an enterprise is to determine what they must contribute in order that the whole may function as his purposes require. Thus, his attitude toward the enterprise is like that of the psychologist toward his patient. Both are first interested in behavior patterns of the whole or the gestalten; "tapping knees" or "doing engineering" is only a method of studying or manipulating parts to understand and to manipulate the whole.

The kinds of persons who have the requisite combination of these characteristics to perform efficiently as entrepreneurs may not be understood or appreciated in large organizations. This failure usually is due to his creative and aggressive attributes. The first concept is that the faculty of creativity is not an easily acquired or capricious quality. Hence, in dealing with "creative" entrepreneurs, we are not dealing with the much maligned so-called "irresponsible creative artists" but with a valuable, relatively scarce human resource which performs a distinct kind of work.

For example, Gheselin (12) writes on the creative process:

> The fact is that the mind in creation and in preparation for it nearly always requires some management. The large objects of management are: (1) discovering the clue that suggests the development to be sought, that intimates the creative end to be reached, and (2) assuring a certain and economical

movement toward that end. The indispensable condition of success in either stage of production is freedom from the established schemes of consciousness. The creative end is never in full sight at the beginning and it is brought wholly into view only when the process of creation is completed. It is not to be found by scrutiny of the conscious scene.

A great deal of the work necessary to equip and activate the mind for the spontaneous part of invention must be done consciously and with an effort of will. Mastering accumulated knowledge, gathering new facts, observing, exploring, experimenting, developing technique and skill, sensibility, and discrimination, are all more or less conscious and voluntary activities. The sheer labor of preparing technically for creative work, consciously acquiring the requisite knowledge of a medium and skill in its use, is extensive and arduous enough to repel many from achievement.

Even the most energetic and original mind, in order to reorganize or extend human insight in any valuable way, must have attained more than ordinary mastery of the field in which it is to act, a strong sense of what needs to be done, and skill in the appropriate means of expression. It seems certain that no significant expansion of insight can be produced, otherwise, whether the activity is thought of as work or not. Often, an untutored beauty appears in the drawings of children, and we rightly prize the best of them because they have wholeness of motive, but they have scarcely the power to open the future for us. For that, the artist must labor to the limit of human development and then take a step beyond. The same is true for every sort of creative worker.

A second concept is that creativity is highly spontaneous or automatic. It is seldom achieved by routine or mechanistic labor. The faculty appears to be one that is possessed in rather fixed degree by any person and, while he can improve his management, he probably cannot increase his creativity. Hence, it is necessary to understand better, both the creative process and the creative person or entrepreneur in order to integrate them into the organization for effective production. Here are Gheselin's observations on how creative production typically takes place:

The faithful formalist has no chance of creating anything. (For example) Automatism (or automatic creation) appears to be fundamental in the activity which Henri Poincare observed on the notable occasion when, having drunk coffee, he lay unable to sleep and became a spectator of some ordinarily hidden aspects of his own spontaneous creative activity: "Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination. By the next morning I had established the existence of a class of Fuchsian functions, those which come from the hypergeometric series; I had only to write out the results, which took but a few hours." Though Poincare was conscious, he did not assume direction of his creative activity at the stage described; and as it seems to have been a sort of activity not susceptible of conscious control, apparently, he could not have done so. If he is right in supposing that what he witnessed was typical of processes ordinarily subliminal, then some part of his creative process -- a classical example -- was automation. Production by a process of purely conscious calculation seems never to occur. More or less of such automatism is reported by nearly every worker who has much to say about his processes and no creative process has been demonstrated to be wholly free from it.

A third concept is that the creative person may tend to cause social or group problems within the organization because of the changes or disequilibria his creations induce. But his purpose is not to cause turmoil or disorder; rather, it is to create a new, more advanced order of equilibrium through deeper understanding. Gheselin writes further:

That automatic and conscious production are somehow opposed is not altogether groundless. The constructive nature of the automatic functioning argues the existence of an activity analogous to consciousness though hidden from observation, and we have, therefore, termed it unconscious. The negative prefix suggests an opposition, but it is no more than verbal, not any sort of hostility or incompatibility being implied by it, but simply the absence of consciousness. Yet a real opposition between the conscious and the unconscious activity does subsist in the limitations which the former tends to impose on the latter. The established possessions of consciousness have a way of persisting, particularly, when they are part of a scheme, and of determining behavior, including a large part of that which is unconscious or imperfectly conscious If this were not so, our psychic lives would, of course, have little stability.

But, this conservative tendency hinders the introduction of anything fundamentally new. The first impulse toward new order in the psychic life is, therefore, as it must be, an impulse away from the clearly determined, from all that is most easily attended to and that most forcefully imprints itself upon the attention. That is, it is an impulse away from the conscious activity already in motion or potential, which would simply reduce it to itself. In the sense of this aversion, it is an impulse toward unconsciousness. This is the real opposition to which I have referred, this reaction against one another of the old order which is more or less readily realizable in the focus of attention and the potential new order developing, and often competing against it in obscurity. It is not the two activities which are opposed, the conscious and the unconscious, but the principles acting in them.

The restlessness of the inventor is unending because he is adept in realization, he has an inordinate appetite for discovery and the ability to satisfy it. He is often a specialist, with less psychic inertia than the average man and, sometimes, with less stability. But, he is not inclined, as some imagine, to mere wandering, to dizzy excursions away from the determinate. He is not a tramp. He is drawn by the unrealized toward realization. His job is, as Wordsworth says, "the widening the sphere of human sensibility . . . . the introduction of a new element into the intellectual universe." He works toward clarification, toward consciousness. That opposition between the conscious and the unconscious activities in creation which we have noticed is only superficial, or rather is only initial The new order which creation is concerned with has an affinity for consciousness.

But, because any new movement of the psychic life can find its freedom only outside consciousness, or at least in some degree of dissociation from consciousness, it has always at first the aspect of adventurous departure from the known, insofar as it is not altogether sublimal. This casting loose the ties of security requires courage and understanding. It requires some courage to move alone, often counter to popular prepossessions, and toward uncertainties. And, to move free of the established, requires the understanding that the established is not absolute, but is only instrumentality of life, is justified only by the service it renders to life, and has no meaning apart from vital needs.

> For the desirable end is not the refreshment of escape into whatever novelty may chance to offer or impose itself, but the discovery of some novelty needed to augment or supplant the existing possessions of the mind. This is as true of invention in the arts and in pure science as it is of the so-called practical inventions, the immediate use of which escapes no one.

The aggressive and active qualities of the entrepreneur also may tend to cause disturbances in stable social organizations. Thus, the boldness and audacity of entrepreneurs may stimulate adverse reactions as they endeavor to effectuate their creative theories and designs within otherwise stable organizations. For example, Torrance (5) reports:

> One important piece of recent research (S. E. Asch - "Studies of Independence and Submission to Group Pressure") paints a rather alarming picture concerning the extent to which we are susceptible to "brainwashing" in its broader sense. Asch generated a disagreement between single individuals and small groups concerning a clear and simple matter of fact in the immediate environment. Only one-fourth of his subjects adhered to their own correct judgments when confronted with the different and erroneous judgments of groups.
>
> Research findings indicate that certain individuals show a generalized willingness to oppose others and disagree when the situation requires it. In a series of studies of the personality requirements for survival, such individuals were found to produce superior results in the form of more adaptive behavior in survival situations, willingness to take calculated risks, and unwillingness to accept defeat. In our studies of USAF jet aces in Korea, we found that this characteristic was typical of the ace when compared with his less successful colleagues. To begin with, he managed to get into air-to-air combat only because he was unwilling to take "no" for an answer. He has made a practice of testing the limits in opposition to accepted procedures and tries to obtain maximum results from himself, his aircraft, his flight, and the situation.
>
> If willingness to disagree is related to individual ability to adapt, it is only reasonable to expect that group processes are affected accordingly. Willingness to disagree has meant the difference between survival and failure to survive in group situations. For example, individuals in survival situations are usually more willing to try strange

> foods than groups. A person alone has only his own conservatism to overcome. When groups did make this adaptation, it was usually the result of some member's disagreeing and saying, "I'd rather eat this than starve." In some cases the effect was immediate; in others, it came only after time.

In the same vein, Maclaurin (13) reports:

> Since the principal social obstacles to change occur at the outset, the innovator, as an individual, takes his place along with the pure scientist and the inventor as a key figure in material progress. To succeed, his imagination must be keen, though tempered with "business judgment". He must have the steady persistence to overcome obstructions, fear, and possible disaster. He must also have the capacity to pick able associates, to retain control and, yet, to delegate authority (a rare gift), and to inspire loyalty. And he must be bold, yet capable of instilling confidence in his financial supporters. Innovations, in fact, may be becoming inherently more difficult. The current trend toward emphasizing smooth human relationships as the principal qualification for administrative responsibility tends to militate against the rise of innovators to top positions. Executive committees of enterprises are often afraid to choose a "strong man" for fear of his disruptive force.

It would be incorrect, however, to assume that executive committees, or boards of directors, as a general rule, all share this fear. It is suggested that, where it does exist, the fear is due to an inadequate understanding of the entrepreneurial personality. While security or tranquility may appear to be the reasons for selecting "safe", or innocuous, persons to top enterprise positions, any reasonable person knows that, not only is the internal organization's tranquility "safe" from him, but that the competitors (or the enemy in war) also are safe from him and that this does not provide "internal security" for the enterprise or nation. Thus, it is believed that the fear is based upon an incomplete understanding of the entrepreneurial authority and responsibility to effective entrepreneurs.

We come thus to one of the central problems of entrepreneurship in society in general and in a large organization in particular. Effective entrepreneurship requires expensive research, development, and production facilities often available only in the large organization. The entrepreneur, either as a team or as an individual, is the keystone or catalyst of industrial progress and economic growth. However, unless deliberate care is taken, the qualities that make a person a successful entrepreneur, may cause him "to fare rather badly at the hands of management". As Wilson[6] stated (12) in relation to the 1956 Inter-Service dispute, "trouble is the price of progress". But, even if care is taken to reduce person-centered disagreement, the entrepreneurial processes may be smothered by the sheer size, diversity and rigidity of the large organization. As Barnard (15) has stated, communication and other related information and decisional problems inherently can limit the size of an organization. Since large organizations often may have the requisite resources for building needed enterprises, society is the loser from these potentially restrictive factors affecting the effectiveness of entrepreneurship.

No panacea is reported here for overcoming these difficulties. However, to a considerable extent the concept of decentralization, such as Cordiner (6) describes, offers an important innovation which has as its object to combine the resource advantages of the large organization with the greater psychological flexibility and the more favorable environment of the small organization, without the limitations of either. It is clear, however, that society and individual organizations, both, should gain from further intensive research on the conditions and nature of efficient performance of the creative, bold entrepreneurial functions. This is a proper subject for at least economists, psychologists, and management scientists. We need to know more explicitly what qualities tend to be found in successful entrepreneurs, how these can be enhanced and developed, how an entrepreneurial team can be synthesized from persons with diverse personal qualities and professional training, how the entrepreneur can be recognized, the extent to which formal organizational structures can aid the entrepreneurial processes, etc. In the remaining sections of this paper we will explore whether and how the rational elements of the entrepreneurial processes can be enhanced by rational methods of analysis and synthesis.

V. Analysis of the Work of the Entrepreneur

In earlier times, the task of designing a physical commodity was based on (what are now considered) "elementary" principles or on no general principles at all. Thus, only primitive commodities were designed; if a more advanced commodity were designed, it was done only by a genius. For example, the horse-drawn carriages were designed and built by craftsmen, but only Leonardo da Vinci could conceive and preliminarily design a flying machine. Now, however, knowledge of the principles of aerodynamics, structures, and power plants is so well developed and so widely disseminated that the average engineering sophomore could design a flying machine incomparably superior to da Vinci's.

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6 Secretary of Defense.

In earlier times, the task of designing an enterprise also was based on elementary principles. Thus, only primitive, one-man or one-family enterprises existed. However, through time, knowledge of more advanced principles in the physical sciences, in economics, in psychology, in the management sciences has grown so much that now it is possible to design more efficient large-scale enterprises, comprising many specialties which are integrated according to logical principles to serve new and diverse purposes.

It is the object here to establish a parallelism between the growth and development of, say, engineering (or other applied science) and of certain elements of the work of the entrepreneur in order to suggest that these elements, like engineering, can be taught, can be organized and delegated, and can be performed by professionally trained persons. If this be true, then society is on the threshold of an important innovation in methods of performing professionally some of the analytic work of the entrepreneur. To this end, some of the elements of the entrepreneurial function are examined below, including the way in which a body of knowledge or science might be developed around them. In this examination, the concern is with the elements of the work which are analytic or technical in their nature, but which are not the result of psychologically automatic production. Specifically, of the seven listed entrepreneurial functions, the elements which satisfy in this prescription are:

a) Methods and concepts for aiding the process of discovering opportunity for enterprise, but not necessarily for discovering the opportunity;

b) Philosophy and methods of defining and synthesizing consistent, efficient theories of enterprise, but not necessarily originating the premises of any theory;

c) Philosophy, methods and criteria for designing enterprises, but not stimulating the design process of affirming the criteria of the enterprise;

d) Methods and principles for portraying the design of an enterprise and for integrating diverse components therein, but not necessarily personally portraying or integrating the components;

e) Principles, criteria and methods for evaluating the risk and reward of entrepreneurial decision and action, but not taking the entrepreneurial risk;

f) Principles, criteria and methods for selecting the timing of entrepreneurial action, but not acting as the entrepreneur;

g) To aid in similar ways in revising the theory, design, scale, and scope of the enterprise.

In the preceding, care was taken to specify or imply that the person whose work is developed there would not be the entrepreneur, but only a professional aid to the entrepreneur. The work so outlined satisfies four essential organizing criteria which distinguish it as a professional kind of work, just as accounting, engineering, etc. are professional kinds of work and are primary functions of most industrial enterprises. These criteria are:

a) an identifiable, teachable body of intellectually challenging methods, concepts, and principles which are essential to performing the work competently;

b) singularity and institutional character of subject matter or focus of work, i.e., the enterprise;

c) the continuity and interdependency of elements in the span of the work process;

d) the ability of the work to serve as a distinct calling, attracting at least some persons who could make it a career, such as law, medicine or theology is capable of providing such calling.

These criteria can be elucidated relative to the work by the following analysis.

A. <u>Common Methods</u>

In many ways, the methods which are characteristic of this newly developing field are characteristic of the many other fields which also are "applied sciences", such as engineering and econometrics. But there is a relatively unique combination of the methods that are applied to this field, and the unique problems to which applied tend to emphasize special refinements and adaptations.

Illustrative of this specialization is Vatter's (16) analogy of a business to an experiment. Vatter's purpose in constructing this analogy is to emphasize that in designing the enterprise, one should do so in such manner that he learns a maximum from the enterprise's operations and so that subsequent operations always can be improved from the experience of the earlier. This is a very useful analogy and a good purpose. Its relative validity can be demonstrated by comparison with the traditional experimental process of science. (See following page for chart.)

The process is the same in both applications, but there are many large differences between applications which strongly affect the way in which the entrepreneurial theory is tested as compared with the way the scientific theory is tested. For example, much of the business "experiment" is irreplicable; each business situation is unique. The law of large numbers does not pertain to much of the entrepreneurial theory and design, nor does statistical decision theory. The time series with which the entrepreneur works are not stationary. The result is that much of the work on design of conventional experiments is not applicable.

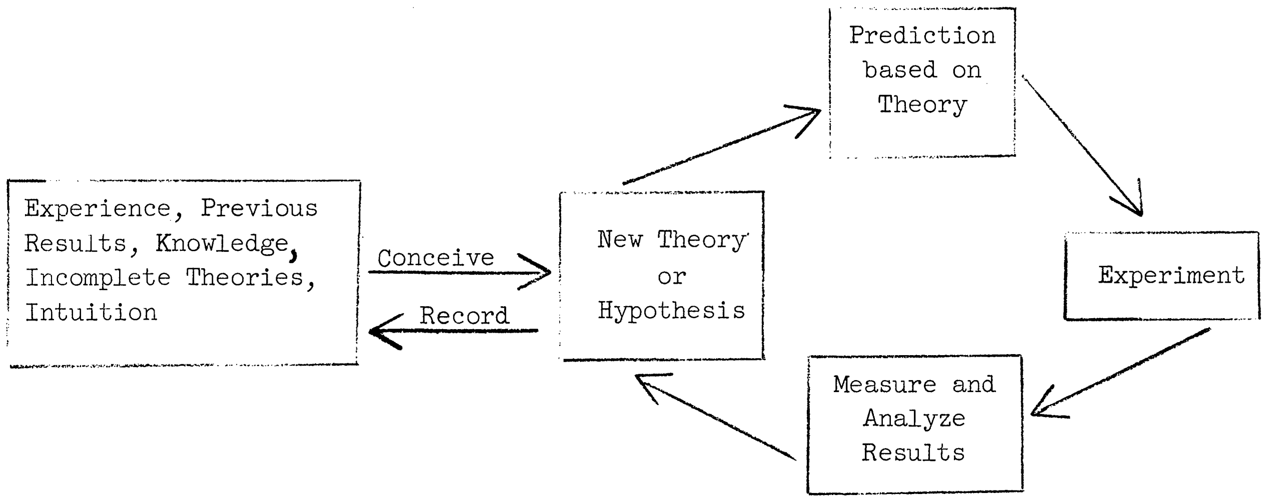
Similarly, the process of formulating theories and hypotheses from assumptions is the same for both scientific fields, such as mathematics or physics, as it is for entrepreneurship. However, there are important differences, such as the more transitory character of the assumptions, the greater difficulty in theory building and providing because of the greater difficulty of stating and testing assumptions and the larger number of relevant assumptions. In addition, the "proof" of an entrepreneurial theorem is, by popular agreement, only determined by the relative success and durability of the enterprise, rather than by a formal, logical proof, even though in some cases success may be due to phenomena over which the entrepreneur has no control or which he did not foresee.

There are other generally recognized methods which are useful in the entrepreneurial analysis and synthesis, such as game theory, queueing theory, operational gaming and monte carlo methods, economics, etc. But, in each case, there usually is or would be a special emphasis or convolution in the method to handle the special characteristics in this application.

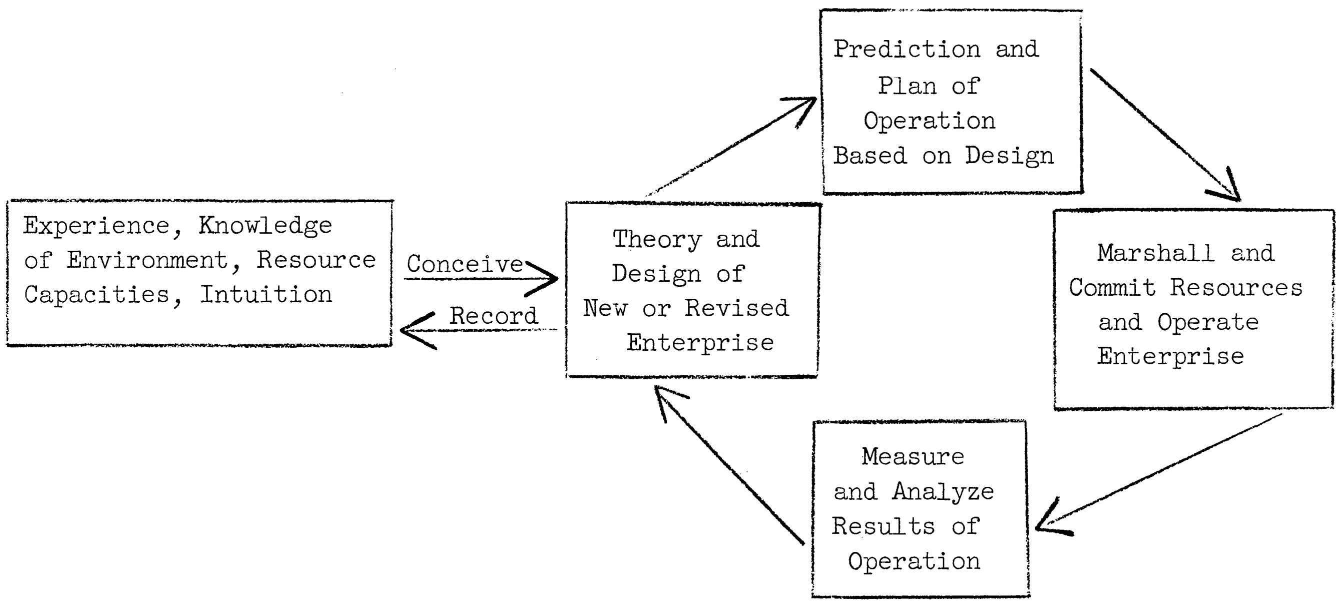
B. Common Focus

Any discipline or profession has a focus characteristic thereof: Medicine focuses on physical and mental health and its maintenance; law on legal relations, etc. Similarly, the work here has a principle concern or focus: the theory and design of the enterprise, including, for example, the scope and content of enterprise, the structure of the information-decision system for its management, etc. The term frequently used within the General Electric Company for work somewhat like this is

SCIENTIFIC EXPERIMENTAL PROCESS



ENTREPRENEURIAL EXPERIMENTAL PROCESS



"Operations Research and Synthesis". The nominal similarity of "OR and S" to "Operations Research" (as that term is used by other enterprises, professional societies, and individuals) is misleading; the focus of the work in OR and S is different from the focus in OR.

General Electric's focus is believed to be relatively unique and considerably more productive of results and insights that enhance the value of the processes of enterprise. General Electric's approach is the result of several years careful study by the Operations Research and Synthesis Consulting Service of the Company in order to determine what subject matter would yield the greatest contribution from the application of these methods and of the personal competence and effort associated with them. The conclusions of that study were, in brief, that OR, as a collection of methods used for ad hoc study of operations, offered only a relatively minor potential contribution to the Company. On the other hand, these methods, if combined with an enterprise-focused, theory-building and design function, often could make large and important contributions.

These conclusions have been substantiated in a number of ways. Firstly, while application of these methods to improve operation of existing resources has been useful, there have been occasions in which, from the point of view of the enterprise, restricted or local optima were obtained. Indeed, in some cases, the results even were in conflict with the broader entrepreneurial purposes. Secondly, as Passer (9) indicates:

> ". . . the most significant manner in which to increase economic welfare is not through better administration of existing resources or changes in the distribution of income, but through applications of science (as with entrepreneurial innovation) which increase the national income." (Words in parentheses are mine.)

Levinson (17) states Passer's principle in a reverse kind of way in commenting on the relative contributions of Operations Research in war and in industry.

> OR should not be sold on its war time contributions. In the war, there was constant introduction of new weapons, "and improvements made in their operations through OR sometimes ran to several hundred percent. In industry, a five to eight percent improvement through OR may be high. The reason is that many companies have had long experience with their operations and have made rather good operational decisions. Even so, OR is well worth the money it costs."

If one translates his observations, he sees that when there were innovation and change -- which are the concern of the entrepreneur -- operations research did make large, important contributions in synthesizing, testing and improving new systems embodying these innovations, establishing criteria for their operation, etc. Often, this testing could be done without building any physical model, but by various methods of simulation. But, where operations are static, Levinson reports OR can offer little. Levinson's logical flaw is that he does not recognize, apparently, that industrial systems or enterprises are as dynamic as the military weapon systems, and that change and innovation are the constancy. True, some elementary operations within industry may be relatively stable, but combinations of the operations, the purposes for which used, their relations to other operations, etc. typically are not stable. It is in these, as they relate to the theory and design of the enterprise that OR, as augmented to these broader synthesizing and testing functions, can make its greatest contribution.

A third area in which experience indicates emphasis on better allocation of existing resources or better administration of existing operations at the expense of effective entrepreneurship does not achieve social purposes as well as innovation and progressive change is in economic planning. Capitalist nations which have resorted to arbitrary controls on allocation, such as through rationing, price control, etc., have stifled entrepreneurship and, thereby, have succeeded only in compounding the problems of having insufficient goods and services to allocate within the economy. Of course, the communist nations have recognized the importance of the technological innovation wrought by the entrepreneur and attempt to perform this function on a "planned" basis.

The entrepreneur thus, is a permanent integral part of the economic and industrial paraphernalia, at least so long as there are change, innovation and progress. The social and economic importance of the entrepreneur, together with the rationality of many of the supporting processes and methods, dictate the eventual development of a profession dedicated to serving the analytic and synthesizing needs of the entrepreneur in the indicated function. This profession will or should have social purpose as high as the medical profession's.

C. Continuity and Interdependency in the Entrepreneurial Processes

The process of defining the theory and design of an enterprise is much like designing a living organism or an engineering system. It must be carried out at two distinctly interrelated levels. The entrepreneurial, or its analogue, the systems, level is concerned with how the whole can and should behave according to the abilities of its components and the conditions in its environment. The managerial level is concerned with managing, in accordance with the entrepreneur's criteria, the components of the system or enterprise as it actually behaves in its environment.

The continuity that is required in the entrepreneurial analyses is due to the fact that when one is studying or designing the behavior of complex organisms or enterprises he usually has not the time and the flexibility of perspective simultaneously to study and design the complex components. He must assume operating characteristics of the components. If the state of the art on any component is fixed and, hence, delimits its operating characteristics, then that limit becomes an internal boundary condition on the operation of the component and, in turn, of the whole. Indeed, the interrelation between the two levels, the whole and the components, is due to the fact that the state of the art of the components changes, with resulting changes possible or required in other components of the system according to the effect of the initial change on the operation of the system.

The result of the distinctness of the two levels is that the engineer who designs a component of a system or the manager who manages a component of an enterprise has known reassuring limits within which he freely may adapt or modify the design or operation of his component. If there is technological or social change which affects his component, and if he can achieve new operating performance levels, the result of the change can be incorporated by the entrepreneur or systems engineer into a new performance for the whole, together with the new performance required of each other component. Thus, the entrepreneur also is free to direct his attention toward the whole and how well it performs so that the components are integrated in relation to that whole and its performance measures.

An incident is cited here in which Wooldridge (18) describes in one instance how the need for the systems engineering approach was recognized. In reading this citation, the reader mentally can substitute "manufacturing" for "computer" and "marketing" for "bomb sight". He would then have a similar visualization of essentially the same problems encountered in designing an enterprise.

> I will tell you in advance that there has been one very important major principle established in recent years by the very extensive activities of our government in the field of military electronics. I shall then have no more to do than simply call your attention to its existence, and how it obviously applied to the field of automation.

As a vehicle for developing the points of interest, let us consider the field of airborne radar. The first airborne applications of radar were in bomber planes, to provide the navigator with means for obtaining position fixes at night or above the overcast. There were also early applications of radar equipment to night-fighter aircraft, thereby permitting a (radar controlled) gunfire attack.

Now, once radar equipment had been put into aircraft to facilitate navigation to the general vicinity of the target, it was natural that someone should propose a combination of radar with bombsight or fire-control equipment to permit actual blind attacks to be made against enemy targets, rather than just the accomplishment of navigation to the vicinity of the target. The military organizations approached this matter in what was to them a normal way. They employed what I shall call the "black box" method. For each weapons project, they assigned to a suitable officer and staff of the military organization the systems management responsibility. In turn, this military project team made arrangements for a suitable contractor to provide what was to them simply a black box -- a radar designed to be suitable for use with the bombsight or fire-control equipment currently in use by the service in question. The theory was that the radar equipment would be delivered, designed to military specifications supplied by the customer, into the hands of the military project organization, and would then be combined with the usual bombsight or fire-control computer, installed in the necessary airplanes, and connected together by military people to provide the hoped-for capacity for all-weather operations.

All this was neat, tidy, and reasonable -- and it suited the military organization. There was only one thing -- it didn't work. The trouble was that, when put together, the radar and computing equipment were generally found to interact upon one another in obscure ways that had not been anticipated. There were a number of reasons for this. As only one example, there were important differences in the character of the target data supplied by optical tracking, with which bombsights and fire-control computers had previously been used. The angular accuracy with which a piece of radar equipment determines the position of a target is usually quite a lot less than the accuracy with which a human observer can set cross hairs on a visual telescope image of the target. What was not so well anticipated was a set of subtle effects on the performance of computers that were caused by the jitter of random variation in target data arising from the basic characteristics of radar. These properties of the radar data in some instances rendered completely inoperable computers that had performed very satisfactorily in their past optical applications.

It did not take them long to recognize that a radar bombsight is not obtained by adding a radar black box and a bombsight black box, but rather must arise out of a single integrated development in which the design of the radar is intimately affected by the bombsight into which it is to work, the design of the bombsight is strongly characteristic of the radar which is to supply it with data and the procedures for employment of the new equipment are similarly tailored to the special properties of the new techniques. In other words, a highly technical systems integration activity was required. The solution to the problem required that the operationally expert, but technically unprepared, military project people assign to technical people the over-all responsibility for the design of a single, integrated combination of radar, computer and methods of operations. This they began to do.

VI. Emergence of the Entrepreneur-Manager and the Entrepreneurial Team

Entrepreneurs, in the manner of Edison, Westinghouse, or Vanderbilt, largely are vanishing, or at least, are becoming increasingly infrequent. The particular combination of conditions, such as laissez faire at its height, minimal social awareness and surveillance, opening of vast frontiers, breakthrough in applied science, together called forth such types of entrepreneurs as "tycoons, industrial barons", etc. Since the enterprises they originated served useful purposes, they tended to outlive their founders and they, indeed, continue to constitute a substantial majority of the contemporary industrial organizations. But, as the conditions changed, a new class of entrepreneurs has come to the helm. These tend to be drawn from the ranks of salaried administrators or managers. But, in their new role, they are more than "managers"; they must become entrepreneur-managers.

The great importance of the entrepreneurial function in economic growth and social progress suggests consideration of the possible consequences of salaried managers assuming the entrepreneurial function so that any relevant, useful inferences may be deduced on how the function can be performed always more competently. To do this it is necessary to assay the differences between efficiently managing <u>for</u> an entrepreneur and efficiently managing <u>as</u> an entrepreneur (or as a member of the entrepreneurial team).

Some of the differences and factors follow: Firstly, the abilities, insights, training, characteristics that often make for success in "managing for" may be inconsistent with and do not necessarily predict success in "managing as". There are obvious reasons. In "managing for" one often must focus on and become expert in the functional component managed rather than the enterprise of which the function is a component part. Superior ability in the component is no necessary indication of superior ability as an entrepreneur. The successful engineer, accountant or other who failed as an entrepreneur-manager is a familiar story. The ability to accept finally the risk of entrepreneurial decisions, or to be the person to whom "the buck finally is passed", is not necessarily developed or often not required in expert professional work. The aggressiveness of the entrepreneur often is only a hindrance to the functional manager.

The creative tendency -- to break with established order and to innovate -- so necessary in the entrepreneur may be incompatible with the proper performance of functional work in the enterprise. For example, there <u>are</u> real reasons why accounting methods and philosophy should change but slowly. In particular, the psychological "role" of being an expert engineer or accountant is different from that of the entrepreneur. Aptitude for one does not imply aptitude for the other. Often, it is observed that a "strong" entrepreneur or leader will tend to collect around him persons who are not also strong and who will not disagree with him, but who will implement for him. If he is a genius competent in all relevant fields, this may be an adequate basis for the entrepreneurial function during his tenure, but often not after. In addition, it does not usually train and develop competent successors. These questions surely indicate the need for further and deeper understanding of the motivations and abilities of successful entrepreneurs, so that these could be recognized, enhanced and used as the basis for selecting and training entrepreneur-managers, both in large and small organizations.

The changed conditions which largely have obsoleted the early types of entrepreneurs also have tended to obsolete the entrepreneur as a single person. The functions and tasks of building and growing an enterprise within the current economic, technical, and social structure are highly complex, requiring diverse knowledge and skills. In order to innovate and to grow an enterprise, the personnel thereof must possess the knowledge and skills in some minimum degree. The diversity of the skills and knowledge is so great that it is virtually impossible for one person adequately to possess them all. Yet, in the entrepreneur's deliberative and decision-making processes, it is necessary that these be not only just "represented in" but that they be part of the intellectual apparatus that performs these deliberations and makes these decisions. For example, if the entrepreneurial deliberations involve some aspect of finance, it usually is not sufficient to ask the advice of the financial manager or specialist. Rather, it is a prerequisite to full and informed deliberations that the financial manager have the aggressiveness, opportunity and responsibility to examine the assumptions and theories, as well as their implications from a financial perspective, as if he were himself the entrepreneur. Indeed, this is why he should be a member of the team which functions as the entrepreneur.

The tendency, therefore, is toward the growth of "entrepreneurial teams". These may be formally constituted as "management councils", "executive committees", and informally constituted as the president's personal confidants, etc. The emergence of the group or team as the entrepreneurial agent also imposes severe changes upon the character of the individuals therein.

The "strong" or dominating leader instead of encouraging and facilitating the free flow of information and concepts within the group often tends only to restrict the flow and, thereby, to reduce the "scope of judgment" that can be brought to the situation by the participants. He thereby restricts the contribution from the team often to only his own judgment and insight. These seldom are as perspicacious and broad as the team's. This practice may have been adequate for near-genius entrepreneurs, such as those mentioned above and at their earlier times when the entrepreneurial function, responsibilities, and, opportunities were not as complex as in our modern industry. It does not appear to be adequate today. Thus, one responsibility of the team members, and especially of the team leader, is to create the interpersonal trust and the environment conducive to such free exchanges.

Greenwalt[7] (19) warned industry "that it must somehow preserve the creative genius of the uncommon man . . . in all progress. The great question is how to develop within the framework of the group, the creative genius of the individual . . . the stake is both the material one of preserving our most productive source of progress and the spiritual one of insuring to each individual the human dignity which is his birthright. Unless we can guarantee the encouragement and fruitfulness of the uncommon man, the future will lose for all men its virtue, its brightness, and its promise."

---

7 President, E. I. Dupont de Nemours and Company.

Thorner (20), an industrial psychiatrist, has reported some experiences in enhancing creativity and ensuring progress. In some instances he observed technologically "wrong" decisions were made because the relative personal or organizational power of the several persons advocating one decision or other was the determinant of the decision, rather than the logic and validity of the respective arguments. Through further studies of this type he then became able to predict the outcome of decisions based upon the power status of individuals participating in the decisions, regardless of the validity of their respective positions. These findings led to further study on methods of generating conditions for creativity within the enterprise. These varied from methods for developing work assignments to advising his client-president on understanding and overcoming the impediments to good communications among the members of the management team. An interesting determination in regard to work assignments was that in the higher, but not exclusively in the "top" levels of management and of technology it is more favorable to creativity and progress to assign each person to do largely what he most wants and is intellectually endowed to do. He found that any gaps in the total required work, after it has been assigned on this basis, then can be collected together and assigned to administrative personnel for routine handling.

This brief survey of the emergence of the entrepreneur-manager and of the entrepreneurial team is not intended to be complete or exhaustive at this time. Its primary purpose is to develop the idea that in modern industrial organizations we are witnessing a fundamental metamorphosis in the entrepreneurial agent. In view of the importance of the function in economic and social progress, it is a subject deserving much research and study on the personal and group processes and conditions which enhance the performance of the function.

VII. Dynamic Relationships in the Modern Enterprise

Three different functionaries in the modern enterprise have been considered here: the entrepreneur-managers, the functionally-oriented operating managers and workers, and the entrepreneurial analysts or scientists. Consider now some of the dynamic relationships among them as they conceive, construct and operate a modern enterprise.

Initially it is noted that, in practice, any particular position almost never will be wholly and exclusively characterized by only one of these kinds of work. Rather, in all positions, in any enterprise there will be some element of each, but with significant differences in their composition. The possible differences in composition will be much like the possible imperceptible shadings that exist between adjacent colors in the spectrum, whereas with colors from widely different portions of the spectrum, there will be easily detectable color differences. In this sense, virtually all employees will have some entrepreneurial responsibility, but the chief executive will have significantly more than the janitor, etc. In particular, it is desirable that the inventive-innovative contribution of the creative entrepreneur be a universal responsibility of all employees. However, incorporating the invention or innovation into the theory and design of the enterprise cannot be an equally shared decision. Ultimately, there must be for each enterprise or component thereof a single locus at which authority and responsibility for this decision resides, whether it be a board of directors, a management council, a president, a foreman, or other. The methods of delegation by which the chief executive delegates certain authorities and responsibilities to sub-enterprises and the entrepreneur-manager or managers thereof, is well known and treated in the literature.

One primary point of contact and interplay between the entrepreneurial functions and the managerial functions would be in planning. Indeed, in response to the vice president's question cited earlier, an effort was made to illustrate -- by the example and its analysis -- that the entrepreneurial functions are the antecedents of planning. Other important points between the entrepreneurial and managerial work would be, of course, in organizing, integrating, and measuring operations of the enterprise. For economy and pertinency the discussion is limited to planning as the point to illustrate these dynamic relationships. Use the planning data classes and functions and the entrepreneurial functions, both developed earlier to illustrate this interplay.

Given structural data and planning methods, the technical work of planning is itself a task requiring high competence, continuity of application and substantive knowledge, and specialization for the more complex situation. The entrepreneur's responsibility is to provide to the various managers or managerial planners the design of enterprise, including planning criteria, policies, scope, so that they may be reflected in operating plans for the enterprise. Thus, the entrepreneur provides the boundary conditions within which the manager manages the enterprise or the worker works. Of course, there is continuing "feed back" between the entrepreneur and the manager, as is illustrated in the chart which analogized the operation of an enterprise to the experimental process.

The relative role of the entrepreneurial analyst in this process is illustrated by the following: (a) testing the assumptions, theories and design of the enterprise which, thereby, define the planning criteria and the planning information and decision structure, but not making the planning decision; (b) anticipating management information needs according to entrepreneurial objectives, so required data can be researched and made available for planning purposes when required. In this process he determines from the shifting theory and design of the enterprise, the information and data which will be necessary for logical, consistent managerial planning.

These do not cover the full range of specific functions for the entrepreneurial analyst (those were summarized earlier). They do illustrate, however, the kind of role which he plays in the enterprise in relation to the managers. He develops, in cooperation with others, principles, concepts, criteria, etc. for the enterprise which are used by the manager in operating the enterprise and by the entrepreneur-managers in affirming the theory and design of the enterprise. His role in this process is analogous to the systems engineer in systems synthesis and design.

Smith (21) posed some strategic "Questions the Business Leader Should Ask Himself" which, in a general kind of way, illustrate questions toward which the entrepreneur-managers and entrepreneurial analysts address themselves, e.g.

> "Does Management distinguish between symptoms and causes?"
>
> "Does Management (entrepreneur-managers) frequently ask itself, 'In our industry, what are the fundamental tasks we perform? 'Do the executives take time to think about major trends?', etc."

These are good questions, but it is believed they do not go far enough. The entrepreneurial analyst described here provides an instrumentality to seek answers to such questions continuously and in depth, but also to discern how variations in the answers affect the theory and design of the enterprise, so that they can be acted upon by the entrepreneur-managers.

A similar extension of ideas can be derived from the proposition described by Felton (22) on the enterprise as a whole. Note its similarity to the systems synthesis concept expressed by Wooldridge.

> The crying need in marketing management today is for greater conceptual skill --- the ability to see the enterprise as a whole and to understand how the various functions of the company and its sales organization depend on one another.
>
> Marketing cannot be effective if it is considered from a marketing point of view alone . . .

> For the marketing officer, this means continual compromise and negotiation with other departments of the company. These compromises -- or, better, adjustments -- will be less hard to take as he develops a company viewpoint and understands why they must be made. For the president or executive vice president, the proposition just described means that "coaching" all department heads in conceptual skill -- the ability, as Robert L. Katz described it, to see the enterprise as working whole -- is one of the most effective ways of helping <u>any</u> department, marketing included, have to battle narrow, specialist viewpoints, and can count instead on a meeting of the minds in top-level conferences (not necessarily agreement), the better off they will be.

Not only does the entrepreneurial analyst "see the enterprise as a whole," as Felton suggests, but he provides the depth studies necessary to determine optimum behavior for the enterprise as a whole. Thus, there is not only a rational basis for the "compromise and negotiations", but, also, for optimal design. That is, it is still <u>necessary</u> but no longer <u>sufficient</u> for good will and conference-type teamwork among the functional managers alone to achieve optimum enterprise design. Such overall studies, as in the case of the new "systems" engineer, are best made on a continuing basis and best made in depth. Through the rational concepts and designs they provide for the entrepreneur-managers, the task of integrating the different functional needs around the conference table to which Felton refers is reduced to a rational process for obtaining the common good.

Consider now a proposition by Katz (23) which also illustrates the need for entrepreneur-managers to have conceptual or theory-building and design abilities.

> At lower levels of administrative responsibility, the principal need is for technical and human skills. At higher levels technical skill becomes relatively less important while the need for conceptual skill increases rapidly. At the top level of an organization, conceptual skill becomes the most important skill of all for successful administration. A chief executive may lack technical or human skills and still be effective if he has subordinates who have strong abilities in these directions. But, if his conceptual skill is weak, the success of the whole organization may be jeopardized.

But again, the entrepreneurial analyst can enhance or facilitate the entrepreneur-manager's conceptual processes as well as carry the logically formulated concepts to inductive or deductive conclusions.

Usually, this will require depth research and analysis to achieve the conclusions. However, the value is indicated by the fact that often such rigorous logical analysis leads to conclusions that are not at all obvious. A nice example of this is cited by Bello (24):

> It is the mark of a great theory that, beginning with certain intuitive concepts, it erects a series of relationships, which, rigorously extended, lead to propositions that are not at all self-evident. Thus, the intuitive basis of relativity theory would have seemed reasonable to Aristotle, but its conclusion that energy and mass are exchangeable would not.
>
> While information theory does not contain anything so dramatic as $E = mc^2$, it does contain one conclusion of great subtlety that continues to astonish its most diligent students. It is a conclusion that, by extension, has great significance for designers of computers and automatic factories on the one hand, and neurophysiologists on the other. And, there are those who believe it may one day have significance in the everyday (i.e., non-electronic) affairs of men.
>
> The striking conclusion is this: After setting up the relationship between channel capacity, bandwidth, power, and voice, Shannon goes on to prove that if an information source produces information at a rate that does not exceed the channel capacity, there exists a method for putting the information through the channel and recovering it at the other side with negligibly small error. Simply stated, this means that a channel, no matter how noisy, can give, as a limit, ideal performance -- in short, perfection from imperfection.

Equally productive methods of analysis and synthesis are available to entrepreneur-managers and entrepreneurial analysts. The prerequisites to tapping these methods are first, the entrepreneur-managers high logical, conceptual ability in concept formation for the enterprise, followed by rigorous analysis and extension of the theory to logical conclusions. This latter is the role of the entrepreneurial analyst whose work is being developed here.

Consider also methods of organizing the team which is to carry out the studies and work of the entrepreneurial analysts (not of the entrepreneur-managers). The work presumably could be done by a team whose members are organizationally scattered in the other functional components of the enterprise, e.g., marketing, engineering, etc. This team, then, would formulate optimal theories and designs of the enterprise, reporting their work through their respective entrepreneur-managers. Any compromise or integration of their results, then, would be accomplished by conference within council of entrepreneur-managers.

The other alternative is to designate the work as a new function of the enterprise. This alternative permits more objectivity by the team and it makes it possible for the manager of the entrepreneurial analysis team to participate in the management council as one of that group while the team members could work with functional specialists as required. By this method, the team's manager can bring the views and concepts developed in this new functional work more directly into the council's deliberations. In addition, this alternative is consistent with the principle already well known in at least psychology and systems engineering: that the whole is greater than the sum of the parts. Studying the behavior of the parts does not reveal the behavior of the whole. Thus far, several Departments of General Electric, each of which is a highly autonomous enterprise, have established Operations Research and Synthesis teams or projects. In some cases, they are pursuing their work essentially as described here. The great majority have elected the separate functional component as the method of organization rather than as a part of the other functional components. It is too early to compare the results of each method with any degree of reliability or significance, although both are being studied.

VIII. Illustrations

In order to fix ideas more specifically, a few simplified examples are cited, particularly in relation to the entrepreneurial analyst.

(1) A producer of a large complex product. In an enterprise which is engaged in the design, manufacture, and marketing of a large complex product, there was a change in one aspect of the enterprise which had extensive ramifications in the whole of that enterprise. Specifically, the product designers were studying the use of a new method and facility for certain design analyses. One of the designers and then the general manager perceived that in order to make best use of the new method and facility, changes would be necessary in other aspects or functions of the enterprise. It became clear that it would be possible to change the product from a custom-engineered design to one which would be designed from standard components and components with a standardized generic shape and configuration. The economic feasibility of the new facility depended also upon the technical and economic feasibility of this change in the basic concepts and method of designing the product. Upon analysis of the total system in relation to this change, it was found that the change in product design

concepts, in turn, depended upon the technical and economic feasibility of many other changes, such as, the marketability of the redesigned product, its relative operational efficiency in the customer's system, the methods and economy of its manufacture, the methods of drafting its plans, the new pricing and competitive policies which the redesigned products would allow or require in the market place, the advertising and sales promotion theme for the redesigned product, the changes in the basic manufacturing theory and design of facilities in order to adjust to anticipated changes in character of demand and of production, etc. In addition, it was necessary to redesign methods and procedures affecting personnel so as to adapt to the human and social needs in the new environment. These, in turn, affected what could be done in the technical processes.

Before the change in method of design computation could be made, it was necessary to interpret it and its derivative changes or implications in virtually all other operations of the enterprise so that the enterprise as a whole could be redesigned and restructured to accommodate the new operating characteristics of that one element of the enterprise. The redesign of the enterprise required a co-ordinated and integrated study of the business as a whole and of its components, such as marketing, manufacturing, engineering, advertising, and personnel policies and procedures. For most effective redesign, the study group needed the ability to manipulate diverse concepts or principles, such as, in electrical engineering, mechanical engineering, systems engineering, manufacturing engineering, market analysis, economic analysis, game theory or competitive strategy, communication and information theory, psychology and group dynamics. The output from their studies is a new design and structure of that enterprise; it is a new way of "doing business". The overall design, in turn, is translated into the brick and mortar and the detailed design for all components of the enterprise by the members of those components, and in such manner that the design of each component is reliably consistent with the objectives and concepts of the whole.

(2) A "small order problem". An independent firm of consultants recognized expert in the methods of operations research was invited by the general manager of a business to study a problem which that enterprise was facing in relation to excessive numbers of small orders for its product. The consultants made a thorough study of the situation and devised methods for determining the break-even points in handling the orders, the "costs" of not providing service to customers who do not order large quantities, etc. The result was a set of decisions the general manager was to make on these costs as to how far he would be willing to sacrifice service to customers for economy in handling orders. After these decisions were made, the consultants then

would devise a decision rule to be applied by the inventory clerks to each incoming order to determine whether it should be accepted.

Before authorizing the application and utilization of this decision rule, the general manager reviewed with others in his company, the work the consultants had performed and the general problem before the business. Some of the participants in these discussions had been trained in the systems synthesis approach to design of enterprise discussed here. In the review, the general manager and the others brought out many related facts on the business, some of which are as follows. Some customers purchase small quantities on first orders, and then standardize on the product for larger quantities after the design has proven satisfactory. Obviously, these must be handled in a special manner.

Questions were raised in the discussions as to the effect of refusing to take orders below the critical size upon the marketing structure. Obviously, it would mean a larger demand upon the dealer and distributor structure, and would require they be geared to handle that larger volume of business, which would come from sources which had dealt with the factory for the small orders. They would mean a different level of inventory and quality of sales-service must be provided by the dealers and distributors. It would also necessitate a better communication network in order to determine how particular sectors of the market were behaving. The interposition of the distributors and dealers between the customers and the factory for those orders also would alter considerably the character of the demand placed upon the factory; it would change composition of order sizes and would introduce transients into the demand series according to the distributors' ordering practices. Thus, the factory inventory level and the criteria for determining inventory level and sales trends would have to be revised. The composition of order sizes to the factory could be changed significantly by a change in the distribution structure. This change to the factory could lead, in turn, to changes in the way in which the orders were handled throughout the data processing network and in the character of the shop, i.e., whether a highly specialized job shop or a mixed shop with some long runs and some short runs. This led to consideration and analysis of the daily labor content of the average incoming small orders, and to the possibility of utilizing separate low-overhead small custom production shops for these orders. This became an optimizing problem in balancing the advantages of special service from the small shops and better order sizes in production shop against the limitations on how big a small shop can become before it begins to require overhead equivalent to the large shop or until it takes so much work away from the production shop that it reduces the efficiency of that shop.

At the same time, it was realized that the segregation of small orders to small, geographically-dispersed low-overhead shops would reduce the amount of "paper work" and alter the optimal design of the data system. Inasmuch as a medium-scale computer was being considered for this purpose, this change had to be reconciled in relation to the total program. Also, the change in the composition of the orders to the shop would effect the methods of shop loading and scheduling which should be used and this is related to the complexity of the methods and size of the computer which would be necessary for handling these functions.

When these changes were tested for their impact on the marketing operations, it became evident that the several possible internal changes would permit changes in delivery and service. In order to evaluate the levels in each of these that would be desirable, it was necessary to evaluate customers' real service needs, ability of different competitors to provide these needs, cost to the business of facilities to provide competitive service. In viewing the competitive situation in relation to the kind of business which the enterprise was operating, the general manager also realized that an important question he should answer is -- "in what business are we?" There were many answers, ranging from a business only to develop, manufacture and supply the basic raw materials of the industry to fabricators who would make the finished products, to a business which encompassed all processes from raw materials development and manufacture to finished products manufacture and merchandising. The former would permit managerial and engineering personnel to concentrate on homogeneous operations and functions of a highly technical nature. The latter would combine into one business the highly technical with less technical activities involved in high intensity merchandising and in competing with "fly-by-night" small producers. As this question was probed further, it became clear to managers that there were a multitude of different business scopes which they could adopt, but for each there would be a different basic design of the enterprise, and incidentally, a different best solution to each special problem, such as the small order problem. At this point, the managers began to refer to the project as the "nature of the business" study rather than the "small order problem".

Of course, in the business study that grew out of the small order problem, there is full opportunity to use all relevant scientific or "operations research" methods. However, these methods now are combined integrally with managerial deliberations and planning; the OR methods have been incorporated as part of a total system of analyses, reports, and studies involved in managing and in the evolutionary re-design of the enterprise. The end results of the studies then include a clear understanding of the business scope and a design of the information-decision system of the enterprise which will permit each participant to have the information he requires to make decisions which will be "best" from the point of view of the business as a whole. This applies not only to order size criteria, but also scheduling principles and methods, inventory levels, advertising and promotional policies, etc. It also permits the specialists in the functional components to study and devise methods and procedures for those components with assurance that it will be both possible and convenient to test the impact or interrelation of changes in that component on the operation of the other components and of the enterprise. Of course, the continuing changes in the environment and technology of the business necessitates a continuing study of this type in order to assure that the business adapts by small evolutionary changes, rather than through major re-organizations -- which usually are tardy adaptations to an accumulation of numerous small changes. It is in this sense -- adapting complex businesses to and facilitating change -- that OR, as broadly conceived, and as a continuing study, helps entrepreneur-managers "manage progress"

Once this deeper understanding of the business was achieved by the principal managers, it became possible to build a team of scientists and analysts, or to retain outside consultants to work at the detailed study level with assurance that they would not be led to restricted optima by their working on problems of arbitrarily restricted scope or by lack of comprehension of the interaction of the many facets of the enterprise each on the others and on the whole.

IX. Conclusions

In this treatise the course of reasoning has departed from many contemporary philosophies, teachings and concepts on management. However, it has been for a purpose: to create a new awareness of a little-remembered function, the entrepreneur. The objects in doing so are to emphasize the role of the entrepreneur in economic growth, to express views on the role of "concept" (idea, theory, design and their formulation) in entrepreneurship, and to suggest the entrepreneurial sciences and scientists as a major innovation for aiding entrepreneur-managers in performing that function. Thus, it is sought to enrich the literature on management by raising it to a new level, by reconciling its principles with the socially and economically more general principles of entrepreneurship.

The need to depart from established concepts and to cite idea-fixing examples derives, it is believed, from the existence of a special language and vocabulary which have developed in the extensive literature on business. It predominantly emphasizes "management" and "Managers" almost to the exclusion of analyzing the kind and nature of the role and function which they may perform in the economy and the society. This literature has derived primarily from studies and experiences in "managing" on-going organizations. For example, Brown (25) as typical of the authorities in the field notes the existence of the "proprietor" (or entrepreneur), but neither identifies, describes, nor analyzes his contribution, his work, his role, nor how to provide for them. Smiddy (26) observes the essence of the entrepreneur's role and contribution: in discussing problems in industrial organization and communication he indicates that these often would not arise "if the owner's goals, objectives and design of business scope were responsibly and ably provided." By identifying and analyzing his functions, the purpose here is to develop methods for providing these and other related contributions both ably and responsibly.

Because of the general orientation of business literature to what "managers do" rather than what role and function they play in the broader economic and social scene, the term "entrepreneur" is relatively foreign. As a result, its meaning and nature cannot be described in that literature with the full richness and connotation which it should carry. The difficulty in being unable to convey the full meaning of a foreign term is a common occurrence in linguistics. It is illustrated aptly by Hardin (27):

> "Any one who has really learned a foreign language knows that some thoughts can be more readily expressed in one language than in another. The comparative study of any two languages will reveal some points of view that are built into one language, so to speak, but not into the other . . . a poignant example . . . (is) the meaning of the French 'viellard', the Spanish 'viejo' and the German 'alte' - all terms implying respect and affection - is certainly inadequately represented by the English 'old man' which implies the decrepit rather than the venerable. Do we have such a poor opinion of old age because we have no simple honorific words for it? Or do we have no words for this status because we do not honor it? . . Out of the work of such men as Sapir, Malinowski, and Whorf, have emerged two very important generalizations (or probably, better 'tendencies') about man and his languages: (a) Every word is a hypothesis about the nature of the world and every sentence is a complex of hypotheses; (b) We can think only those thoughts that our language permits us to think." (Words in parenthesis are mine in order to incorporate his later arguments.)

As further evidence that the issue of language and meaning is not merely idiomatic, he then cites that our Indo-European language unconsciously led Newtonian physicists to postulate "ether" and that it took, literally, an Einstein "to escape from this tyranny of language" and develop his special and general theories. The change in linguistics largely eliminated the "need" for either to explain and understand certain physical phenomena. The difficulty probably would not have arisen if Newtonian physicists had thought and spoken in the Hopi Indian language, because that language embodied concepts more conducive to the special and general theories of Einstein than the theories of Newton. In the same sense, escape is sought here from preoccupation with "the manager, managing, and the managed" so that it is possible to treat with role and function of which the manager is but one element. For this reason, the writer has examined a broader horizon to determine <u>those business activities and functions which are necessarily performed, even before any "manager" appears on the scene</u>. In addition, the relationship of these activities and functions to similar ones which are carried out while the manager is on the business scene is traced. Then, it is demonstrated that these functions transcend the usual connotation associated with "managing" but are more appropriately associated with the entrepreneur.

The tendency in analyzing the work of managers has been to subdivide and examine that work in greater and greater detail. This is necessary to understand "what managers do". For example, Smiddy (28) in commenting on this subject speaks well for the many scholars of "management" on their process of analysis and perspective of observation:

> It is always difficult to analyze so complex an amalgam of efforts as those that constitute the work of successful and professional managing. We need to try mentally "to stop" an apparently continuous process energized by many diverse forces in an effort to see and understand the parts which make it whole. We must, in these instants of observation, draw heavily upon our experiences in order to reference it into our system of thought with ample definition.

In contrast to attempting to "stop" and examine stroboscopically the managerial process internal to the administration of an enterprise, the attempt here has been to observe dynamically the relationships between the enterprise on the one hand and the entrepreneur's and the enterprise's environment on the other. Perhaps, this difference in perspective can be illustrated analogously. Consider a football player as an analogue of the enterprise. Then, the stroboscopic studies of managing, typified by Smiddy's description, are concerned with such aspects of the football player as his rate and efficacy of cerebration, neuron firing time, muscular reaction time, energy conversion rates, etc. On the other hand, the entrepreneurial studies take these for granted, but treat with his role and function in the team (society) in terms of blocking, tackles, forward passes, "plays", etc. Both these perspectives are necessary and, indeed, are complementary. The latter perspective was taken here because the entrepreneur is believed to have been under-emphasized in past studies and because his rôle and functions are of equal importance in the total social and industrial processes.

The final object is to suggest that, having recognized clearly the basic functions of the entrepreneur, certain things can help the entrepreneur-managers of large organizations to perform those functions more efficiently. A particular suggestion is that the subject matter of the new "Operations Research" will be the research and design supporting the rational elements of the entrepreneurial processes. Experience in psychology and in systems engineering suggests that study and rationalization of the enterprise as an entity is accomplished best by direct study of the behavioral patterns of that entity rather than through the rationalization of the behavioral patterns of the components or parts of the entity.

Thus, organizationally, this is interpreted to mean the instrumentality to perform the studies of the whole should be a distinct component of the enterprise cooperating with the other components rather than a sub-component of the other functional components of the enterprise. Of course, these other components themselves profitably can employ organizational sub-components which would use similar methods in similar kinds of studies of their own internal operations. This corresponds to the experience in systems engineering that often the same methods, useful in designing the system as a whole, are useful also in designing the components. The reason for having a different organizational group assigned to each is, as before, the need for perspective and continuity of study.

In conclusion it is recalled that there is an increasing tendency for hired "managers" to manage enterprises now <u>as</u> entrepreneur-managers rather than <u>for</u> entrepreneurs. This tendency is especially strong in large organizations with widely dispersed ownership. Because these large organizations necessarily will provide the major entrepreneurial contributions to society in the more technical fields, there is an urgent, pervasive need to learn more about what types of persons perform well as members of entrepreneurial teams, how such teams are best composed, how the entrepreneurial scientists can be incorporated into this team. Of course, research is needed to accelerate development of the entrepreneurial sciences and of the adaptations of the scientific methods and techniques useful in these sciences. For, surely, the advancement of individual and social material well-being within the conditions of individual liberties, free enterprise, and economic competition is a worthy endeavor of science.

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OPERATIONS RESEARCH AND THE SCIENTIFIC METHOD*

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Operations Research is not a branch of mathematics although it uses mathematics to study operations. It is a new tool of management and not a new way of doing management. It won't supercede management. Operations Research can be viewed as similar to any other research effort. It is quantitative and is concerned with the use of the scientific method to study operations.

An operation is here defined to mean a group of men and machines doing a regular job. The repetitive nature of the job is important since the regularity allows the operation to be studied.

While operations of large magnitude have been studied, it is frequently necessary to study first a small problem and progress to a larger problem bearing the overall goals in mind.

The application of the scientific method begins with observation of a phenomenon. It is necessary to look and think. This is the part of the scientific method that can't be laid out by logical rules. Experience, intuition, and judgment are required to find something significant in the phenomenon. Ability and experience are required. Newton was not the first person who saw an apple fall nor was Franklin the first person to see lightning. It is usually possible to select some important variables and relationships between the variables.

The second step in the application of the scientific method in the physical sciences is to set up a mathematical model. This is a formal attempt to describe the relationships between certain of the variables. Presumably the model describes the phenomenon as well as observation is able to detect, but it is necessary to take a closer look.

This leads to the third step which is experimentation. Predictions made by the model can be checked by experiment to determine the degree to which the model corresponds to the natural phenomenon. It is usually necessary to revise the model in the light of the results of experiments.

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* Notes taken by Joseph Hoagbin

The fourth step is to formulate a theory based on the tested mathematical model. The theory will permit predictions within limits but with considerable confidence.

The fifth step is control of the phenomenon gained by the knowledge of the relationship of the variables. The theory permits new designs, and helps in intelligent planning. It is now that the payoff begins.

While much has been written about the theory of Operations Research, it, like physics, is not just theory. Experimentation constitutes a large part of the expense and time consumed in applying the method to operations problems.

Thus the application of the scientific method involves all of the following:

Observation
Modeling
Experimentation
Theory
Control

Once a theory has been formulated, the understanding of additional phenomena grows. Operations Research has increased the understanding of a large number of seemingly unrelated operations.

The question of information flow and material flow is a problem of widespread interest. It arises, for example, in the flow of goods through a production line, through warehouses, and through the distribution to the customer. Consider the interconnections between many factories and many warehouses. It is necessary to consider the cost of shipping to various warehouses, the cost of holding material in warehouses, and the cost of being out of material at any warehouse. It is desirable to balance these costs. Linear programming is a mathematical tool for the study of such problems. The steady state flow of material and information is getting to be of great importance in Operations Research. Problems of non-steady state flow and non-linear programming are also of importance, but not as much has been done in this area.

Another theory that has increased our understanding of material and information flow problems is the theory of waiting lines or Queueing Theory. A railroad station, or an operator at one point in a production line has some average capacity. Many times it is sufficient to balance the average serving capacity with the average rate of the arrival of items to be served. This is true when there is great regularity in the times of arrival of things to be served and the times required to give the service. However, when the rate of arrival varies and the serving time varies, waiting lines may develop.

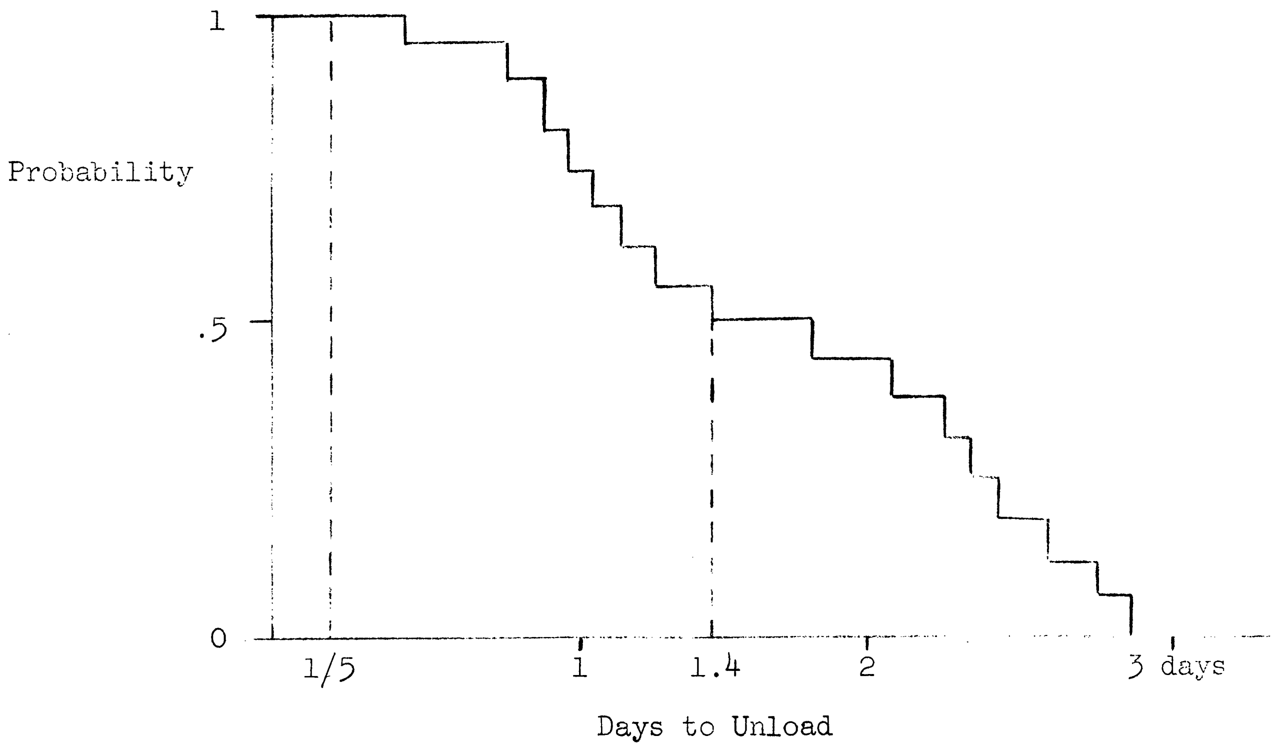
Consider a single dock in a harbor. Incoming ships must unload at the dock before they leave the harbor. Let us assume that the dock has an average capacity for unloading one ship per day. If the average rate of arrival of ships is less than one per day, there appears to be a proper balance of unloading facilities and work load. However, the individual unloading times may vary from, say, half a day to a day and a half. Also the ships may not arrive regularly even though the average is one per day. Sometimes ships find they must wait since two or three arrive at the harbor on the same day, or a ship arrives while another is being unloaded. Even if the capacity for unloading is greater than the average rate of arrival of ships, it is still necessary for some ships to wait. Let us assume initially in this example that ships arrive at the average rate of eight in ten days.

There is an actual case in which a similar harbor was considered a good harbor because of the short waiting lines. To reduce congestion at other harbors, it was decided to increase the shipping load slightly at the efficient harbor, but immediately the waiting line doubled. At first it was suspected that employees at the dock were not working as efficiently or that there was evidence of sabotage. Analysis showed, however, that what happened was to be expected and that the waiting line length is very sensitive to the rate of arrival of ships when the rate of arrival is near the rate of unloading. The same theory was found to apply to other seemingly dissimilar problems:

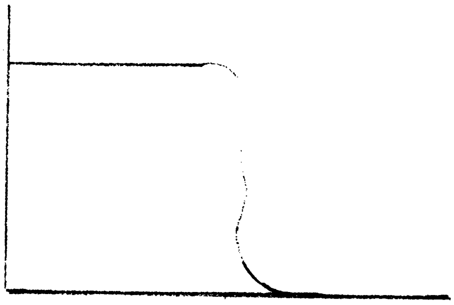
Servee	Servor
Ships	Docks
Planes	Clear Runways
Autos	Toll Booth
Messages	Cable
Paper Work	Clerks
Inoperative Machines	Repairman
Buyers	Reordering

The general theory permits one to make quantitative statements about many individual cases. Since the waiting lines fluctuate, it is desirable to study averages and probabilities rather than the exact length of the waiting line at a particular time.

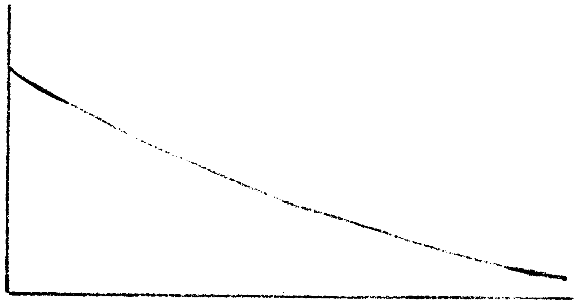
In the study of such problems, it is necessary to first observe fluctuations in rate of arrival and rate of service. We can take data that will permit us to find the probability that the waiting line will be longer than any specified number and data that will permit us to find the average waiting time.



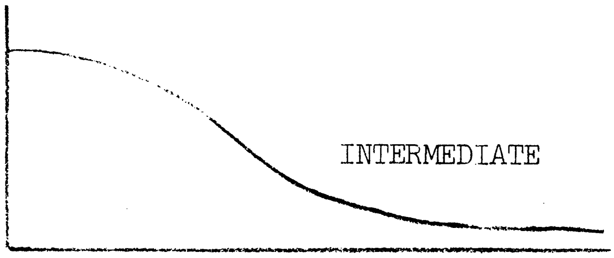
In the case of the ships and the dock, it would be desirable to make many measurements of the times required to unload a ship. In the figure above, assume seventeen such times were measured and plotted as shown in the order of increasing time. The individual times to unload vary between about a quarter of a day to two-and-three-quarter days. Note that the probability that the unloading time will exceed one-fifth day is one. The probability that the unloading time will exceed two-and-three-quarters days is zero. Note that about half the time the unloading time exceeded about 1.4 days. When sufficient measurements have been made to give confidence, one can draw a smooth curve in place of the step curve in the figure. In taking such observations, it is possible to get curves of many shapes as shown in the following.



CONSTANT SERVICE TIME



EXPONENTIAL SERVICE TIME



INTERMEDIATE

If we stand these regions on end we have geometric figures having a base of length unity. If we multiply unity by the average unloading time, we get an area equal to the area of the region. Thus the average service time is equal to the area of the region under the curves (drawn to the proper scale).

Similar data can be taken and plotted for the time between arrivals of ships. From the data one can determine the average rate of arrival.

In many problems, it is found that the rates of arrival are randomly distributed according to the so-called Poisson distribution. If the arrivals are Poisson distributed, the times between arrivals are "exponentially" distributed. That is, the curve relating time and the probability of getting a time of a certain length or longer is roughly of the shape shown and labeled in one of the figures previously shown. The exponentially distributed times are important in Operations Research because they are the easiest to analyze and because they occur in many of the cases studied. Telephone calls and the arrivals of cars at toll booths have been found to be Poisson distributed.

In attempting to model the ship and dock example, it is wise to begin with a simple case first. We will continue to consider only one dock, and we will assume that the arrivals of ships are Poisson distributed, hence the times between arrivals are exponentially distributed. We will assume also that only one ship can be served at any one time and that other ships that have arrived must wait their turn. We will assume that the rule is first-come first-served.

Let us call the rate of arrival of ships A and the rate of unloading the ships S. That is, in the long run, an average of A ships per day arrive and S ships per day are unloaded. Let P_n be the probability that exactly n ships are waiting in line. Then it can be shown that under the assumptions we made (see Appendix):

$$P_o = 1 - \frac{A}{S}$$

In the harbor example, we have been considering A equals .8 (8 ships in 10 days) and S equals 1. Hence A/S equals .8 and the probability that there will be no waiting line at all is .2. Another way of stating it is that .2 or one-fifth of the time there will be no ships waiting in the harbor to be unloaded.

It can also be shown that the average number L of ships in the harbor will be:

$$L = \frac{A}{S-A}$$

In the example we have been considering

$$L = \frac{.8}{1 - .8} = \frac{.8}{.2} = 4$$

We are now in a position to see what will be the effect of diverting additional ships to this harbor. If the average rate of arrival of ships is raised to nine in ten days we have:

$$L = \frac{.9}{1 - .9} = \frac{.9}{.1} = 9$$

and we see that the length of the average number of ships is more than doubled.

The model tells us that as A is made larger and approaches S the waiting line rapidly grows longer. Waiting ships cost money and increasing the unloading facilities costs money. If the ships are owned by the same company that owns the dock, it is possible to balance the cost of waiting and the cost of increasing facilities so that their sum is a minimum. The total waiting time can be expressed from what has gone before. When a ship arrives it finds on the average L ships already in the harbor. Each of these ships will require on the average 1/S th of a day for unloading. Hence the total waiting time will be the product of the number of ships and the time required to unload each ship. Let t equal the time required to unload a ship and W be the total time the newest arrival must wait, then:

$$t = \frac{1}{S}$$

$$W = Lt = \left(\frac{S}{S-A}\right)\frac{1}{S} = \frac{1}{S-A}$$

When ships were arriving in the harbor in our example at the rate of eight ships per ten days, the average time of waiting in the harbor was:

$$W = \frac{1}{1 - .8} = \frac{1}{.2} = 5 \text{ days}$$

When the rate of arrival was increased to nine ships in ten days, the average waiting time increased to:

$$W = \frac{1}{1 - .9} = \frac{1}{.1} = 10 \text{ days}$$

In an effort to reduce waiting lines, it is sometimes possible to regularize rates of arrivals or rates of serving. Although we will not provide the demonstration here, it can be shown that if arrivals are carefully scheduled so that they are all evenly spaced the mean waiting time can at best be halved if the rate of serving is not also similarly regularized. Also if the rate of serving is regular and the rates of arrival are not, a similar reduction is possible in the mean waiting time. Frequently, it is possible to regularize one or the other, but not both of these rates. In such cases, it is necessary to consider whether the cost of regularizing one or the other is worth the reduction in waiting time.

The theory has been developed to consider multiple servers or channels, but these cases are too complicated to consider here. Increasing the number of docks or of toll booths or of cables will increase the value of S, but one must consider whether the increased cost is worth the reduction in waiting time.

Some consideration has been given to problems in which the waiting line must be made less than a specified length. A store owner will attempt to keep the waiting line at zero where problems of stockage occur. That is, he realizes that if he is out of a particular item, the customer won't wait but will shop elsewhere. Here again, the shop owner must balance the cost of carrying an inventory with the cost of losing a customer.

Appendix

The probability that there will be no ships in the harbor is affected by the number of ships that might arrive when there are no ships and by the number of ships that might leave when there is only one ship. The relationship expressing how this probability changes is:

$$dP_o = S\ dt\ P_1 - A\ dt\ P_o \qquad (1)$$

When steady state is reached this probability stops changing with time and we can write:

$$\frac{dP_o}{dt} = 0 = SP_1 - AP_o \qquad (2)$$

Similarly, if we consider the number of ways the system can be put into the state where there is only one ship in the system, we see that the probability of having just one ship in the system depends on the rate of arrivals that tend to put the system in the "one" state and on the number of departures that tend to put the system into the "one" state. We can write for the steady state:

$$\frac{dP_1}{dt} = 0 = AP_o + SP_2 - (A + S)P_1 \qquad (3)$$

It can be shown that, in general

$$\frac{dP_n}{dt} = 0 = AP_{n-1} + SP_{n+1} - (A + S)P_n \qquad (4)$$

Hence it is possible to write each of the probabilities in terms of the others, and, in particular, in terms of P_o.

$$P_n = P_o \left(\frac{A}{S}\right)^n \qquad (5)$$

We would like to evaluate P_o in terms of A and S.

We know that the sum of the probabilities must equal unity or

$$P_o + P_1 + P_2 + \ldots\ldots = 1. \tag{6}$$

From (5) and (6) we can write

$$P_o \left(1 + \frac{A}{S} + \frac{A^2}{S} + \frac{A^3}{S} + \ldots\right) = 1. \tag{7}$$

But the series in the brackets can be evaluated and

$$1 + \frac{A}{S} + \frac{A^2}{S} + \frac{A^3}{S} + \ldots = \frac{1}{1 - \frac{A}{S}} \quad , S > A \tag{8}$$

From (7) and (8) we can write

$$P_o = 1 - \frac{A}{S} \ . \tag{9}$$

We can now write (5) as

$$P_n = \left(1 - \frac{A}{S}\right)\left(\frac{A}{S}\right)^n \tag{10}$$

Note that the solution of the foregoing equations was made possible only by the assumption that A is less than S. The ratio A/S is sometimes called the utilization factor.

We would like to find the average number of ships in the system. It can be shown that:

$$P_1 + 2P_2 + 3P_3 + \ldots = L \ . \tag{11}$$

By the use of (10) and (11) we can show that

$$L = \sum_n nPn = \frac{A}{S - A}$$

Those interested in additional reading on Queueing Theory may consult:

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COMPUTING MACHINES AND THEIR USE IN OPERATIONS RESEARCH

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The concept of an automatically sequenced computing machine was first propounded by Babbage about 1840. It was not until one hundred years later that Professor Howard Aiken achieved the first large-scale computer in the electromechanical computer, Mark I, built by IBM for Harvard. This first computer was relatively expensive and slow by present standards. The work turned out did not exceed greatly what could have been obtained by the same resources spent on well organized human effort. However, significant advance was made in that the computing results were almost error-free.

ENIAC was the first large-scale digital computer to use electronic techniques, and was inspired by the scaling-circuit techniques developed for nuclear physics. This computer was completed in 1946 at the University of Pennsylvania by Eckert and Mauchly for the Army Ordnance Corps. It brought about an immediate 1,000 fold increase in computing speed.

These large-scale computers are not brains and do not solve problems, but rather are tools for mechanizing solutions that have been devised by human brains. On the other hand, they are powerful tools for coping with intellectual drudgery and dealing with organized complexity. In addition to lowering computing costs, the use of electronic techniques made feasible the handling of complicated and intricate problems. Today we have computing devices that exceed our ability to utilize fully. Whereas at first primary attention in this new field was given in the problems of computer development, there is at present considerable emphasis on how best to use large-scale computers in order to realize their inherent capability.

The Bureau of Census is now using UNIVAC for the tedious task of tabulating collected information. They have completed over 40,000 hours of productive machine time and have learned a lot about how to use machines, although they feel they have not learned as much as they had hoped.

The effort began five years ago when UNIVAC was scheduled for delivery to the Bureau. Because there was uncertainty about whether the computer would be delivered on time, it was necessary to proceed on the assumption that the data planned for UNIVAC processing might have to be handled on punched cards. Accordingly, punched card procedures were completely developed, and partly for this reason the first program for UNIVAC amounted to an adaptation of the punched card procedures. When the computer was delivered, a trial run of 10 percent of the data was processed on the computer; the rest was processed on punched cards. For this initial trial, it is doubtful that the cost of processing information in the computer was any less than the cost of processing by punched card methods. However, some of the capabilities of the machine were learned, and it was possible later to cut the cost of processing to half that required by punched card methods by taking advantage of the greater speed and accuracy of the computer. They also utilized the large storage capacity to keep a running count of the classes of information desired.

Where calculations are necessary a computer can accomplish the job much more cheaply than any punched card system. For example, with desk calculators the cost of multiplying two ten-digit numbers together is $30,000 per million completed products. A digital machine can do this same amount of computation for about $30.00 and it is likely that future machines will do a million such multiplications for about $3.00 or even less. Addition, subtraction and comparisons are correspondingly cheaper, and these are the important operations for data processing tasks.

Much of the cost in using a computer lies in the formulation of the problem and in gathering and preparing the information to go into the machine. Considerable effort and expense are required to get information into a form suitable for automatic machine processing. The Bureau of the Census formerly divided costs for data collection and processing of decennial Census about as follows:

1)	Gathering source data	50 percent
2)	Editing and transcription	25 percent
3)	Tabulation and computation	25 percent

With present experience and equipment it is possible to cut the tabulation and computation costs by about one-half. Hence, further reductions in this area are of secondary interest to reductions of the other costs. Recent experience has given encouraging indications regarding use of the computer for doing the editing. It is felt that the transcription costs can be lowered by mechanizing collection, but one must be careful not to increase the gathering costs in the process.

Mechanization at the source has the advantage that the gatherer has an understanding of the subject matter being gathered and can recognize obvious discrepancies, such as ten-year-old veterans. The gatherer can help assure consistent source information, can help with the mechanization and to minimize transcription errors.

Mark sensing schemes that perform acceptably under office conditions are not entirely satisfactory for field use. Field experience in Canada has indicated that more than fifteen percent of marked cards may be rejected. As a consequence, our Bureau of the Census is experimenting with a micro-filming scheme called FOSDIC, which was developed at NBS. The collectors can have a document of convenient size that can be marked on both sides with a conventional pen or pencil. By using a lens with a long depth of focus it was possible to work even with wrinkled documents. The microfilming process allows all documents to be put into a smaller uniform size that can be fed directly into the machine.

Our knowledge of the proper use of machines has grown steadily. Scientific problems usually can be neatly formulated as equations and the information can be easily assimilated by the machine. Data processing problems, such as those confronting the Bureau of Census, are considerably more difficult to formulate for the machine, since they are usually not appropriate for mathematical formulation and can be very complicated logically. It is not unusual for such problems to require several thousand lines of coding or detailed instructions for the machine.

In using a machine one needs safeguards against operator errors. If possible the problem should be formulated in such a way that operators can stop and back up when they discover an error. Annotated tapes can help avoid operator error. Also, machine operators sometimes forget that idle time on the machine is just as expensive as productive time. The Bureau of the Census has been able to realize up to 80 percent utilization by using competent help and by carefully planning the work so that mistakes by operators do not lead to long re-runs on the machine. In a segment of a typical recent survey it was found that utilization of the computing facilities varied over the range of 16 percent to 75 percent of the time available.

Experience has shown that the proper use of machines makes possible something close to perfection in error-free information handling and computation. People lose and bend cards in punched card systems. Automatic error checking routines can be built into the programming of a large-scale computer. The Bureau of the Census makes free use of built-in cross checks to determine the credibility of numbers computed by the machine.

There are three general stages in learning to use a computer. In the first stage an effort is usually made to convert the old procedure to the machine. In the second stage one begins to take advantage of the capabilities and accuracy of the machine. In the third stage one learns how to get important by-products and new products from the machine. That is, the machine may now make it feasible to extract certain information, even though it was known beforehand that this information was desirable. Moreover, the machine may be able to get at information that could not have been obtained by the usual manual procedures.

Computers are now finding application in the solution of the complex problems encountered in Operations Research. In this type of problem, equations, if they can be written, are frequently non-linear. The machine employs numerical methods to crank out solutions as functions of parameters. Also, there is the class of problems in which the machine is not a calculator but is rather a logical manipulator.

An example of a problem involving logic more than mathematics is that confronted by the Public Housing Administration. This agency must continually check on occupancy characteristics and economic status of tenants. For example, no family without children can claim the standard exemption for minors, and the amount of the exemption claimed in cases where there are children must be consistent with the number of minors claimed. They must also keep check on whether the financial status of a family has improved to the point where the family is no longer eligible to occupy government housing. Since policing is time consuming, consideration was given to the use of a computer to assist in the task and an experimental trial has been run. One end-product is the reference to appropriate paragraphs for a form letter when it is necessary to write to the supervisor asking for clarification of reported data. The machine is governed by rules of logic rather than by equations. Something as efficient as symbolic logic will have to be developed to state properly such rules and to facilitate the formulation of such problems for machines.

The Air Force is faced with another class of problem in putting together "fly-away" kits. These kits must contain what will be needed to sustain a crew for a predetermined time period without resupply. In making up the kits, account must be taken of weight and volume restrictions, the needs of particular aircraft types for parts for maintenance, and the maintenance history of the particular group of aircraft. Data collected in the past must be analyzed in order to make up a kit for a particular thirty days. New information gathered as time progresses must be taken into account. Project RAND and the McClellan AFB are working on mechanizing the solution of this problem.

The three armed services have coordinated clothing purchases in an effort to get bids that are most advantageous to the government. In accepting bids account must be taken of the bidders' financial soundness, space, ability to produce in the required time, and the past experience with the bidder. After bidders have been screened, there is more that must be done in order to reduce costs to a minimum.

The government buys economic lots of the raw materials such as cloth and buttons. This raw material is delivered to a fabricator who cuts, sews, and delivers the clothing. Hence there is the assignment and the transportation problem that must be solved in order to find minimum costs and yet assure the government of clothing of acceptable quality.* In submitting a bid, the fabricator states his cutting efficiency by stating the amount of goods he will need to deliver a given order for the finished product. The bidder will take into account freight costs, and can submit different bids for different plants and may specify the numbers of units he can produce for a range of bids.

The solution of a typical problem may involve four places where material will be warehoused by the government and twenty plants where clothing will be made. About 700 man-hours are required to get an approximate solution to one of these problems. An exact solution may take 4,000 man-hours. This problem was formulated for SEAC at the National Bureau of Standards and resulted in reduced computation time and cost. Also, less argument resulted because the more exact solution is now easily computed. It is now possible to teletype the bid information to the Bureau on one day and have the solution ready in New York City on the following day. It must be emphasized that not all such problems can be so easily formulated.

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* This problem is discussed in the Naval Research Logistics Quarterly, Vol. 1, No. 1, p. 48: "Linear Programming in Bid Evaluation," Stanley, Honig, and Gainen.

DISTRIBUTION AND SCHEDULING PROBLEMS*

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We start by stating six seemingly different problems of a type often encountered in operations research.

1. Job Assignment. Consider the problem of assigning ten men to ten machines. Assume the 10 numbers required to specify each man's performance (say parts produced per hour) on each machine is known. We will not now be concerned with the difficult problem of determining these performance ratings. When each of the men has been assigned to one of the machines, it is possible to add the individual performance ratings and arrive at what is known as a "rating sum." The problem is to maximize this rating sum (the total number of parts per hour produced).

Real problems of this nature might involve much larger numbers of men and jobs. The Air Force, some 10 years ago, was confronted with the problem of assigning 2,000 men each month to 21 job classifications when given the total number needed in each job classification. The Air Force used test scores to estimate the performance of each man in each job and their effort was to assign in such a way as to maximize the total test score.

2. Transportation Planning. A certain company has a fleet of trucks and several delivery points and loading points. The cost of a trip empty for one truck travelling from any one loading point to any one delivery point is assumed known. Presumably, the travel of loaded trucks is dictated by demand, here assumed to be a known constant number of loads per month between any one loading point and any one delivery point, but the routing of empty carriers is entirely under the control of the company. The problem is to meet all delivery demands but to route empty carriers in such a way that the total trucking cost is minimized.

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* Notes taken by J. Hoagbin

The Navy, just prior to the Korean war, had this problem in the routing of empty petroleum tankers. The number of loads to go annually from each loading post to each delivery post was specified inflexibly for the Navy by the Armed Service Petroleum Purchasing Agency. There were six loading areas and 21 delivery areas, and the time required to travel empty between any two ports was known. The problem was to route empty tankers so as to minimize the total time spent by tankers travelling empty, and hence also to minimize total tanker fleet cost since only the empty routings were left for Navy decision.

The solution of a problem of this type is for a steady-state condition. We have not yet learned how to handle problems involving changing conditions. Thus, after one has once solved a problem such as the tanker fleet problem, one must expect to solve the problem over and over again under a new set of world, and hence, military conditions.

3. Product Distribution. A company has several manufacturing plants and warehouses, all widely separated. The production capacities of the plants are known and the monthly demand at each warehouse is known. The cost of producing a particular item is different in different manufacturing plants but is known. The cost of shipping a particular item from a particular plant to a particular warehouse depends on the plant and the warehouse, but is known for each plant and each warehouse. The problem is to meet the demands at the warehouses but with minimum cost of production and shipping.

In an actual example, a large chemical company solved this problem for the case of 4 plants and 70 warehouses. The problem yielded to a fairly precise solution because shipping costs were well known and are definite. Before applying mathematical techniques to this problem, the chemical company set up a trial and error procedure that involved hand computation. Savings in cost of 8% were realized by the use of this approximate method. The later use of mathematical programming techniques for the solution of this problem resulted in an additional 4% savings in cost.

In another actual case, General Foods had four regions, where products were manufactured and 50 warehouses. The output of each region was several hundred-thousand units per month whereas the demands of the 50 customers and warehouses varied from a few hundred to several thousand units per month. General Foods has reported a saving of $100,000 per year as a result of the successful solution of product distribution problems of this kind.

Incidentally, one might ask whether the problem of where to locate plants and warehouses is a similar problem. The answer is that it is very similar but usually much more difficult.

4. Hide and Seek. John von Neumann[1] has prepared a two-person hide and seek game that is of considerable theoretical interest. Assume that a certain part of a city is selected for the game. The part of the city selected contains 100 street intersections and is, therefore, 9 blocks square. One player is instructed to hide at any one of the 100 intersections. The second player is permitted to search along any one of the 10 streets. If the hider is not found, the seeker must pay him an amount of money depending on the amount specified for the intersection where he is hiding. These amounts vary widely and are known to both players. If the seeker finds the hider, the hider must pay him an amount depending on the value of the intersection. The problem is where to hide, in order to minimize the hider's expected losses, and where to seek, in order to maximize the seeker's anticipated gains.

5. Travel Routing. A salesman wishes to visit each of twenty cities, starting and returning at his home office. He knows the cost of travelling along each of the possible legs of the journey; i.e., he has estimates of the total cost due to automobile mileage, bridge tolls, etc. in travelling from any one of the 21 cities to any other. The problem is to select a routing that minimizes total travel cost.

6. Production Scheduling. A small job shop is confronted with the problem of making 1,000 of a particular part on one machine. Five operations must be performed to produce each part. These operations may be performed in any order, but the machine must be returned to its pre-run setup after the parts are completed. The cost of going from any one setup to any other is known; i.e., the costs (in time) for an operator to adjust the machine to go from any one operation to any other operation is known. The problem is to determine the best sequence of operations in which to perform the five operations so as to minimize total production time required.

In actual practice the problem might involve scheduling about 40 such operations daily in a job shop. One rule of thumb often used by foremen in handling this problem is always to choose as the next operation the one that can be set up most quickly. This is not usually the best solution.

Similarities of These Problems

These six problems may seem at first glance to be less closely related than they really are. Problems 1, 2, and 3 have identical mathematical formulations, and are also essentially identical to Problem 4. Problems 5 and 6 are mathematically identical, and are very closely related to Problems 1-4. All six problems may be formulated as linear programming problems.

Hitchcock,[2] at MIT, and Kantorovitch,[3] in Russia, both proposed the mathematical problem represented by Problems 1-4 about 1941. Independently, Koopmans[4] rediscovered the problem in 1948 his work led Dantzig,[5] and others,[6] to the recognition that this problem is also a linear programming problem and hence susceptible to numerical solution by techniques such as the simplex method.[5] Hitchcock posed the problem originally as in our Problem 3, and gave a computational method that was correct for all except certain special, but important, cases. Kantorovitch posed the problem in quite a different context, and referred to the case of continuously moving earthen hills so as to change the topography from the initial one to some specified new one while doing least physical work; his computational methods seem to have the same flaw as that in Hitchcock's method. Koopmans posed the problem as in our Problem 2, and his computational methods were partially complete[6] and very closely related to the simplex method used by Dantzig[5] to solve this problem. Flood,[7] and others,[5] have developed computational methods free of the flaws in the earlier algorithms proposed by Hitchcock, Kantorovitch, Koopmans, and Dantzig. Kuhn,[8] in 1952, has published a method for this problem that is both correct and probably more efficient than any other yet available for this problem; he has called this the Hungarian Method, and several authors have presented useful modifications of Kuhn's algorithm. Perhaps the problem is best called the Hitchcock-Kantorovitch Distribution Problem. Flood[9] has published an account of the Navy tanker fleet application, the first made for this problem, and has also discussed[10] the interrelationships between all six of the problems presented here.

Hassler Whitney[11] first proposed the mathematical problem represented by our Problems 5 and 6 in 1934, and with reference to a politician travelling from home in Washington D.C. to each of the 48 state capitols and returning home again. The problem is closely related to a problem posed by Hamilton in the nineteenth century (1862, 1884), and discussed by Ball[12] as the Hamiltonian game by König[13] as Hamiltonian Lines. It is also mathematically close to the Hitchcock-Kantorovitch Distribution Problem, a fact that Julia

Robinson[14] first observed when she treated our Problem 1 successfully during an unsuccessful attempt to solve the Whitney Routing Problem (now widely known as the "travelling salesman problem").

Dantzig, Fulkerson and Johnson[15] have applied linear programming computational techniques successfully in solving a few numerical examples of the Whitney Routing Problem. Flood,[10] and various other authors, have recently discussed this problem--but all without real success, and the problem remains open.

In presenting such problems the mathematical formulation is usually given first, and then the applications to various problems are shown. I feel it is more effective to present the seemingly diverse problems first and then show later that they yield to the same mathematical formulation. Actually this is the way knowledge unfolds in practice. A theory usually has many applications, but ingenuity is required to see the similarities between different problems related by the theory.

Solution of the Assignment Problem

We have discussed the assignment problem and related problems. Now we will look at one of the techniques for solving such problems.

First consider the simple array in Figure 1. This is much too small to be of practical importance, but it is large enough

		job 1	job 2	job 3
man	A	6	3	2
man	B	5	4	1
man	C	11	9	5

FIGURE 1

to demonstrate methods for solving larger arrays. The array shows the ratings of men A, B, and C doing jobs 1, 2, and 3. For example, it will cost six dollars per part if operator A makes the part that is turned out on job 1. The part will cost only five dollars if operator B is assigned to job 1. Table I shows the possible job assignments and the rating sums that result.

TABLE I

Assignment Number	Job 123	Rating Sum
1	ABC	15
2	ACB	16
3	BAC	13
4	BCA	16
5	CAB	15
6	CBA	15

We see that assignment (3) gives a minimum total cost of making the three parts.

We have just demonstrated one method of solving the assignment problem. That is, if one is confronted with the problem of finding "best" assignment of men to jobs, one can list all the possible assignments and from among the list pick the one with smallest rating sum. It was possible to solve the 3 x 3 array in this way but the problem of assigning 20 men to 20 jobs would require the writing down of 4.3 million, million, million assignments (4.3×10^{18}). Even a high-speed computer could not sort through all the possible assignments in several lifetimes. In general, in an N x N array, factorial N assignments are possible.

Before leaving this simple example, there is an interesting lesson to be learned about over-all optimization. Note that only one operator in assignment (3) is assigned to the job for which he was best fitted. In fact, man B should be assigned to the job for which he is most poorly fitted if the total cost to the business is to be minimized.

Now consider the array in Figure 2. This is the same array as that in Figure 1 except that 5 has been subtracted from the bottom

	1	2	3
A	6	3	2
B	5	4	1
C	6	4	0

FIGURE 2

row. Table II shows the new rating sums obtained by using the new matrix in Figure 2. Note that all of the rating sums in Table II are five smaller than those in Table I but that assignment (3) is still the best assignment.

TABLE II

Assignment Number	Job 123	Rating Sum
1	ABC	10
2	ACB	11
3	BAC	8
4	BCA	11
5	CAB	10
6	CBA	10

Now consider Figure 3 which was obtained by subtracting 5 from the first column in Figure 2, and by subtracting 3 from the second column in Figure 2. Notice that assignment (3) is still the

	1	2	3
A	1	0	2
B	0	1	1
C	1	1	0

FIGURE 3

best assignment and that it stands out clearly because of the zeros. We have just given an intuitive demonstration of a theorem (anonymous) which states that the "best" assignment is unaffected if a number is added or subtracted from any row or any column of an assignment array. That is, we have shown that if we have an array A and an array B, and if A was obtained from B by adding or subtracting numbers from rows and columns of B, then a "best" assignment determined using A is also a "best" assignment using B.

Now we see the importance of the zeros in Figure 3. Assignment (3) is clearly the "best" assignment for this matrix. We can now be certain that it is also the "best" assignment for the matrix in Figure 1.

Next consider the matrix in Figure 4. In this matrix the ratings are the output of particular operators when assigned to the three machines. Here we wish to assign operators so that we maximize

	1	2	3
A	6	9	9
B	7	8	11
C	6	8	12

FIGURE 4

the total output. Table III shows the possible assignments and the total output resulting from these assignments. Notice that assignment (3) is the best assignment from the standpoint of maximizing production. We will now show that when attempting to determine the "best" assignment

TABLE III

Assignment Number	Job 123	Rating Sum
1	ABC	26
2	ACB	25
3	BAC	28
4	BCA	24
5	CAB	26
6	CBA	23

for maximizing a rating sum in an array like Figure 4, it is possible to change Figure 4 into an array whose minimum rating sum should be found. This technique will allow us to solve all assignment problems in a similar manner.

In Figure 4 let us subtract each entry from the largest entry in the matrix. This will yield the matrix in Figure 5 which was

	1	2	3
A	6	3	3
B	5	4	1
C	6	4	0

FIGURE 5

obtained by subtracting each entry in Figure 4 from 12. Now we assert that the assignment that leads to the smallest rating sum in Figure 5 will give the largest rating sum in Figure 4. Actually, Figure 5 is identical to Figure 2 and we have already seen that assignment (3) yields the minimum rating sum in Figure 2.

Consider now Figure 6. By appropriate subtractions from rows and columns one can obtain Figure 7 and it is seen that all of the

	1	2	3
A	2	4	4
B	4	6	6
C	4	6	6

FIGURE 6

six assignments in Figure 6 are equally good. Thus we have given an intuitive demonstration that there is sometimes more than one "best" solution to an assignment problem.

	1	2	3
A	0*	0	0
B	0	0*	0
C	0	0	0*

FIGURE 7

From Figure 3 and Figure 7 we see that a "best" assignment has been found when one has reduced the assignment array to the point where there is at least one zero for each row and column, and in addition it is possible to select from the set of zeros a subset such that no two zeros appear in the same row or same column. This subset of zeros in Figure 3 is obvious. In Figure 7 a possible subset is indicated by the asterisks.

From the foregoing we have seen that the zeros take on special significance when one attempts to solve an assignment matrix. It should be noted here that it is possible to write algebraic formulae which express what is contained in the array. In fact, in solving the usual form of the transportation problem, it is customary to set up a set of simultaneous linear equations and solve these to get a minimum or maximum rating sum. Emphasis is placed on the technique of operating on the assignment array because of the computer that I have with me tonight.

This computer is capable of assisting in the solution of a 20 x 20 assignment array. The ratings are set in an array of electromechanical counters by means of a telephone dial. Push buttons associated with each row and column make it possible to add and subtract numbers from any row or column. The computer has "covering bars" so that an operator can indicate that particular rows and columns contain zeros. Also the computer has lights associated with each electromechanical counter that permit an operator to give particular zeros special significance. With this computer one can demonstrate and study alternative algorithms for reducing large assignment arrays.

Trial and error is sufficient for reducing small arrays but rules must be formulated for large ones.

The computer was built by the Engineering Research Institute of the University of Michigan with Institute funds. This particular machine was tailored to the particular algorithm devised by Dr. Munkres,[16] one of our mathematicians.

Consider a production scheduling problem like the one in Problem 6, except that we do not require one part to be completed before going to the next part, and consider the array in Figure 8. This matrix shows the cost in time required for an operator to adjust a machine so

	1'	2'	3'	4'	5'
1	I	6	7	7	6
2	6	I	8	8	7
3	6	7	I	7	5
4	4	4	3	I	4
5	5	5	5	4	I

FIGURE 8

that he can go from one of the unprimed operations on a part to one of the primed operations. For example, if he has just completed Operation 1, it costs six units of time to adjust the machine so that Operation 2 can be performed.

Now consider Figure 9 which was obtained from Figure 8 by appropriate subtracting from rows and columns of Figure 8. The capital I's along the diagonal in Figure 8 and Figure 9 were inserted to represent infinity. We did this to assure ourselves that the solution of the array

	1'	2'	3'	4'	5'
1	I	0	1	1	1
2	0	I	1	1	1
3	1	1	I	1	0
4	1	1	0	I	1
5	1	1	1	0	I

FIGURE 9

would not call for going from one operation to the same operation, since, for the example we have in mind, there was a prohibitive cost for repeating any one of the operations.

Figure 9 shows that the operator should do the following in order to minimize the cost in time spent in adjusting the machine, where we have neglected the minor cost met in adjusting the machine for the very first operation and also any cost associated with leaving the machine adjusted for some undesirable operation at the end of this practice run:

First perform operation 1 on the first part. Adjust the machine to perform operation 2 and then perform operation 2 on the first part. Now adjust the machine to perform operation 1 and perform operation 1 on the second part. Repeat the same sequence for the second part and for all 1,000 parts. Next, perform operation 3 on the first part. Adjust the machine for operation 5 and perform operation 5 on the first part. Next adjust the machine to perform operation 4 and perform operation 4 on the first part. Now adjust the machine to perform operation 3 on the second part. Repeat the sequence for the second part and for all 1,000 parts.

Figure 10 shows an array for a travel routing problem where the problem has been reduced to five cities. The array shown is the one that has resulted after appropriate subtraction and additions were performed

	1'	2'	3'	4'	5'
1	I	0	3	5	3
2	6	I	9	0	7
3	4	3	I	9	0
4	6	2	0	I	6
5	0	4	6	9	I

FIGURE 10

on rows and columns of the original matrix set up by the salesman showing the cost of travelling from any one city to any other city. The solution in Figure 10 indicates that the salesman can start at city 1, which we will say is his home city, and should proceed to city 2. From city 2 he should go to city 4, thence to city 3, from 3 to 5 and from 5 back to his home city. In Figure 10 it was possible to solve the travel routing problem after we verify that the solutions of this problem are also unaffected by subtracting a constant from all entries in one line of the array.

Figure 11 shows another travel routing problem involving five cities. Note that this "solution" calls for going from city 1 to city 2

	1'	2'	3'	4'	5'
1	I	0	2	4	1
2	0	I	3	1	2
3	6	4	I	4	0
4	2	1	0	I	2
5	3	4	1	0	I

FIGURE 11

and thence back to city 1. It is not clear how the traveller ever gets to cities 3, 4, and 5. In short, we have not been able to determine by this method the cheapest route for the traveller to take if he wishes to visit all five cities. In fact, much more advanced techniques are required to solve large travel routing problems of this kind unless it just so happens in some particular case that a non-return routing can be found among the solutions to the Job Assignment Problem with the same array.

With regard to the product distribution problem, consider Figure 12.

Warehouse	I	II	III
Demand Units	3	1	2
Cost per unit for Factory I	5	4	7
Factory I capacity 2	X_{11}	X_{12}	X_{13}
Cost per unit from Factory II	3	1	6
Factory II capacity 3	X_{21}	X_{22}	X_{23}
Cost per unit from Factory III	4	2	9
Factory III capacity 1	X_{31}	X_{32}	X_{33}

FIGURE 12

Note that total factory capacity equals total demand. The units of production and demand might be hundreds of thousands of pounds of product. The cost units might be thousands of dollars to produce a unit at a particular factory and ship it to a particular warehouse.

This problem is easily solved as a job assignment problem, writing the array as shown in Figure 13. In Figure 13 we are concerned with assigning a particular unit produced at a particular factory to one of the places in one of the warehouses. The array shows the cost of assigning

Factory		Warehouse I A	I B	I C	II D	III E	III F
I	1	5	5	5	4	7	7
I	2	5	5	5	4	7	7
II	3	3	3	3	1	6	6
II	4	3	3	3	1	6	6
II	5	3	3	3	1	6	6
III	6	4	4	4	2	9	9

FIGURE 13

each produced unit to one of the spaces available in warehouses. Of course in actual practice, one would work computationally with the array written in the form of Figure 12 and even actually explained as in Figure 13.

Figure 12 and Figure 13 are related to the transportation planning problem involving empty trucks and mentioned earlier in the talk. The demand units are now the number of empty carriers required at each pick-up point. The production capacity units become the number of empty carriers released by each unloading point. The cost units become the cost of routing an empty carrier from a particular unloading point to a particular pick-up point.

Unfortunately, there is no time left to consider an example of the hide and seek game. Very briefly, the solution is that the hider hides only at intersections represented by positions in the array that appear in a solution of the job assignment problem with this same array. The hider hides in each of these positions a certain percentage of the time, and these percentages are very simple algebraic functions of the numbers appearing in the array at only these positions. There is a similar computational rule for determining the frequency with which the seeker seeks on each street. As is standard in game solutions, the use of such a playing strategy by the hider ensures a certain maximum expected loss that he can suffer and this maximum is also the smallest such loss that he can guarantee himself. Von Neumann[1] presented the game as an illustration of the fact that every two-person matrix game is mathematically equivalent to some linear programming problem--in this case to the Hitchcock-Kantorovitch Distribution Problem.

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LINEAR PROGRAMMING IN INDUSTRY*

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For hundreds of years mathematics was developed in conjunction with the natural sciences. Very subtle relationships between a few variables were studied. It is possible to express such relationships in differential and integral equations. In contrast to this, many operations problems involve very simple relationships between many variables. Such problems are difficult to handle because of this large number of variables. In a sense, linear programming is a mathematics of complexity. Only recently have methods been developed which give insight into the structure of these relationships.

Let us consider an example of a linear programming problem. The example is greatly simplified but includes the essentials of more complex problems.

There is a certain machine shop with two machines. The machine shop makes two products. These are Widgets and Gadgets. For making a gadget two hours is required on machine one. For making a widget, three hours on machine one and five hours on machine two are required.

The machine shop can sell widgets for one dollar each and can sell gadgets for fifty cents each. Each day twelve hours of time are available on machine one and ten hours are available on machine two. Figure 1 summarizes the conditions:

	To Make a Widget	To Make a Gadget	Machine Time Available	
Time required on machine one	3	2	12	V
Time required on machine two	5	0	10	W
Selling prices in cents	100	50		
Number of each item made per day	X	Y		

Figure 1

* Written by J. E. Hoagbin from his notes taken during two talks by A. Charnes, Purdue University.

The problem is to determine the number of widgets and gadgets to make. That is, to determine X and Y so as to maximize the return for making the two items. We are not concerned with V and W for the moment. They will be considered when we discuss later what is known as the "dual" of this problem.

Let us put another restriction on the problem: only integral numbers of widgets and gadgets are to be made. It is understood, of course, that negative amounts of product cannot be made, and hence negative values for X and Y cannot be allowed.

One way to solve this problem is to write down all the possible mixtures of product as in Table I. For this list we pick the mixture that yields the highest return. In the table we see that mixture (12) is the best. This calls for making two widgets and three gadgets. The return will be $3.50. The mixtures having asterisks must be discarded because they are not "feasible" mixtures in view of the restraints on machine time available.

TABLE I

	Program			Hours	
	Widgets	Gadgets	Return	Machine 1	Machine 2
(1)	1	0	$1.00	3	5
(2)	2	0	2.00	6	10
(3)	3	0	3.00	9	15*
(4)	1	1	1.50	5	5
(5)	1	2	2.00	7	5
(6)	1	3	2.50	9	5
(7)	1	4	3.00	11	5
(8)	1	5	3.50	13*	5
(9)	2	0	2.00	6	10
(10)	2	1	2.50	8	10
(11)	2	2	3.00	10	10
(12)	2	3	3.50	12	10
(13)	2	4	4.00	14*	10

Such a method of solution is entirely impractical in dealing with large matrices.

A second way of solving the problem is to write the equations in X and Y, taking into account the constraints, and then to solve the set of simultaneous linear equations. For example, the requirements that available machine time not be exceeded may be written:

$$3X + 2Y \leqq 12 \qquad (1)$$

$$5X \leqq 10 \qquad (2)$$

Our requirement that X and Y both be positive can be expressed as

$$X \geqq 0 \qquad (3)$$

$$Y \geqq 0 \qquad (4)$$

Our desire to realize maximum return can be written as

$$\text{Maximize} \quad 100X + 50Y \qquad (5)$$

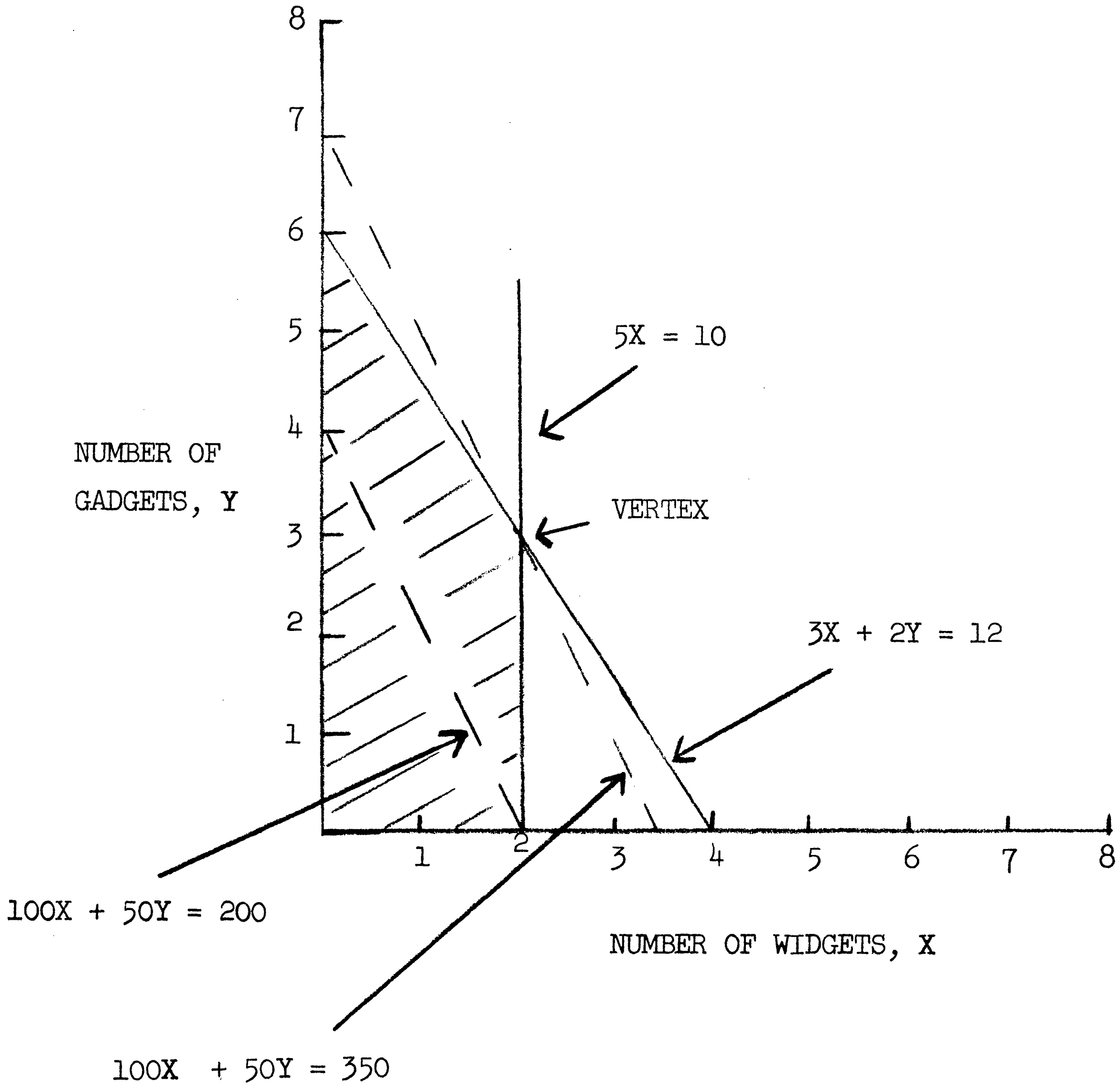

Figure 2

Figure 2 shows graphically what is involved in the solution of these equations. Such a graphical solution is not possible with large matrices since spaces of dimensions higher than three are required to represent the surfaces involved.

In the figure the shaded region is the set from which feasible mixtures can be selected since in it both X and Y will be positive and the available machine time will not be exceeded.

The problem is to find the "best" feasible mixture or the so-called "optimal" feasible mixture. This is the mixture that will make equation (5) a maximum. The dotted lines in the figure show two of this family of equations. We see from the figure that the optimal feasible mixture calls for making two widgets and three gadgets for a return of $3.50.

Note the importance of the vertex in the solution. The solution of a linear programming problem by the solution of a set of equations consists of first finding the vertices of an n-dimensional surface, and then finding which of these is best. Considerable work is required for these steps. There is a simpler method known as the Simplex method that permits one to find first one vertex and then a better vertex if one exists. This process continues until it is apparent that the best vertex has been found. The simplex method is more efficient than a general solution because it is not necessary to find all of the vertices.

So far we have discussed a problem in which we desired to maximize a quantity. There is a theorem that says that every linear programming problem can be made into a problem in which some quantity is to be minimized. The theorem states that every linear programming problem has a so-called "dual" problem associated such that optimal value obtained by solving the maximization problem is the same as the optimal value obtained by solving the dual minimization problem. We will not prove the theorem but can illustrate the solution of a dual problem:

Suppose that you are an outsider and that you would like to rent the machines owned and now in use by the machine shop in our first example. Suppose also that you are in possession of the facts presented in Figure 1 but that you never bothered to calculate X and Y. Your problem is to determine the best rents V and W to offer for the use of the machines.

You realize that there is no use offering V and W smaller than the machine shop now realizes from the manufacture of the two products. The following set of equations describes the situation:

$$3V + 5W \geqq 100 \quad (6)$$

$$2V \geqq 50 \quad (7)$$

$$V \geqq 0 \quad (8)$$

$$W \geqq 0 \quad (9)$$

$$\text{minimize } 12V + 10W \quad (10)$$

Figure 3 shows the plots of these equations and the shaded region of feasible rents to offer. The inequalities (8) and (9) hold because there is no use offering negative rents. This restriction is indicated in the figure by the use of the first quadrant only. There is no point in offering less than twenty-five cents per hour for the rent of the machine one since the machine shop can always make that much per hour on the machine by making its own products. Similarly V and W must lie on or above the line represented by inequality (6).

On the other hand, there is no point in offering too much rent. The dotted lines show two of the family of lines represented by equation (10). Note that the minimal feasible mixture of rents to offer is the mixture that calls for paying $3.50 for the use of the machines.

It is also interesting to note that V and W are indices of the worth of the machines to the machine shop. They tell how much per hour each machine is now earning for the machine shop. They permit the owner to judge the value of increasing available time on one or both of the machines. Thus linear programming can be used to answer quantitatively such questions as whether it will be worthwhile to increase production capacity.

In this example constraints on demand were not considered, but if we restricted the machine shop to making only one widget, the optimal feasible mixture of products would be number 7 in Table I. Also the worth of the machines would change.

In an actual example I know of, a steel company wanted to know whether proposed construction of a new mill to replace an obsolete one was justified. The problem was first studied by considering a few typical products and comparing the estimated cost of making these products in the new mill with the cost of making them in the obsolete mill. These

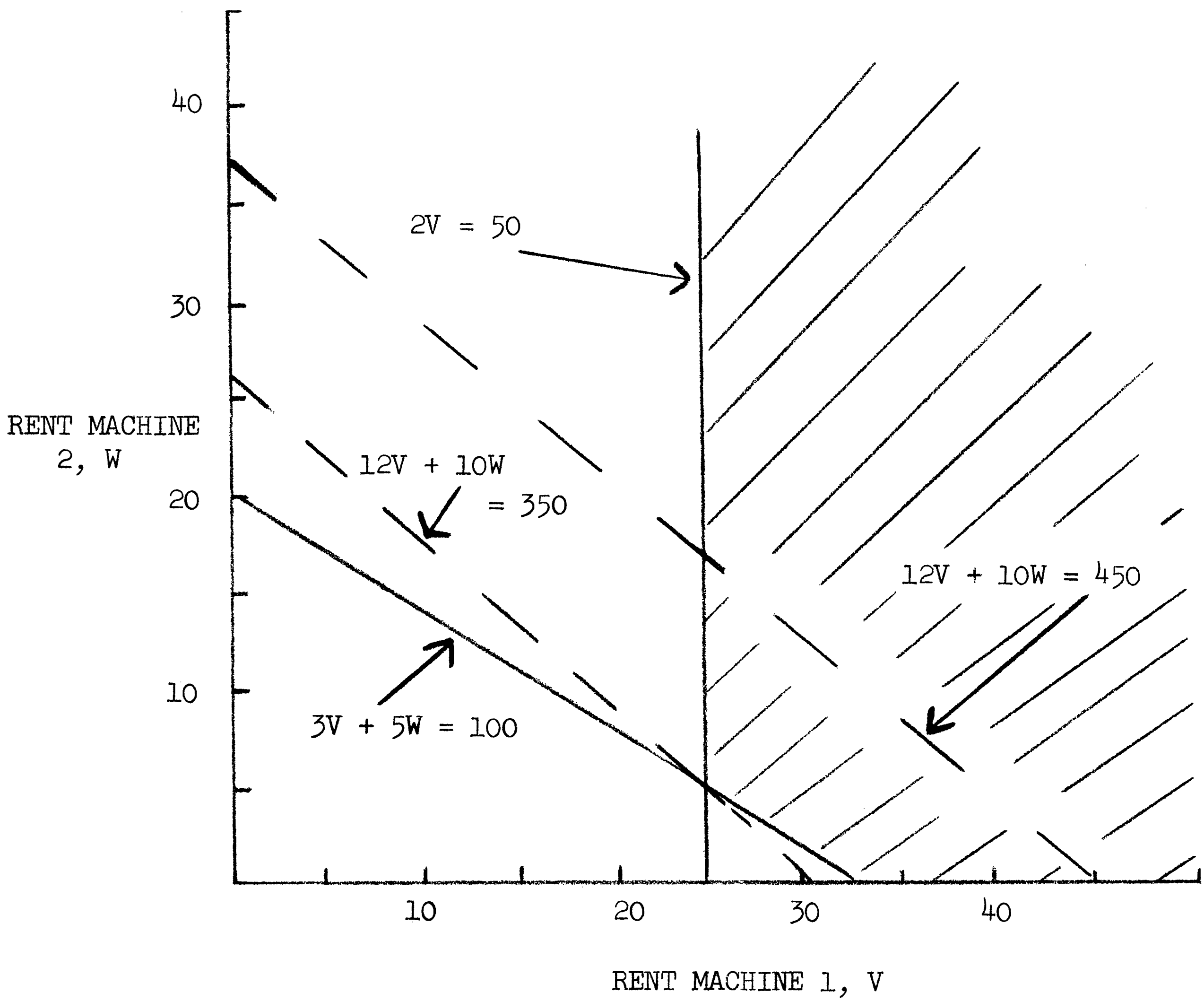
40
30
20
10
RENT MACHINE
2, W
2V = 50
12V + 10W
= 350
12V + 10W = 450
3V + 5W = 100
10
20
30
40
RENT MACHINE 1, V

FIGURE 3

first estimates indicated that a substantial saving would result if the new mill were built. However, a new model of the business was set up later taking into account major products, all existing plants, and the actual demand for the products. This model indicated about twice the return as that previously estimated. Thus another type of programming problem arose: what modifications in the existing capacities would suffice to produce the initially estimated return?

Work in many applications of linear programming has led to the appearance of similar arrays in problems that seem at first glance to be dissimilar. Some of these arrays have turned out to be easier to solve than the general linear programming problem. Much computation can be saved if one can recognize a problem as one of these special cases.

One such special case of the linear programming problem is the transportation problem (which has been used in its own right to solve the problem of transportation of catsup).

Let us consider an example of model approximation.

						Available Time
Machine	I	.198	.303	.388	.103	25
	II	.404	.612	.792	.210	35
	III	.192	.294	.367	.101	30
Units		100	75	40	60	
Product		1	2	3	4	

Figure 4

The matrix in Figure 4 shows the times required to make each of four products on each of three machines. The bottom row shows the number of units of each product required. The right hand column shows the total machine time available for each machine. Any of the machines can completely make any of the products.

In many real situations scheduling is critical only with respect to a relatively few "bottleneck" machines which must be carefully scheduled. The larger problem of considering all machines can then be simplified to that of considering only the few critical machines.

If the entries in the array were all unity, the problem could be considered a transportation problem.

Figure 4 shows that products requiring long times on one machine require long times on all machines. Figure 5 shows Figure 4 after the columns have been multiplied by numbers calculated to bring some of the

	1	2	3	4	
I	.99	.909	.97	1.03	25
II	2.04	1.836	1.98	2.10	35
III	.96	.792	.93	1.01	30
	20	25	16	6	
	1	2	3	4	

Figure 5

entries near unity. Column one was multiplied by five, column two by three, column three by 2.5, and column four by ten. Note that the bottom row was also altered. Each of the entries in the bottom row was divided by the same number its column was multiplied by. In column one of Figure 4, 100 units are required. Suppose these are packed five to the box. Figure 5, column one, just says that it takes .99 units of time to make a box of product one. We see that multiplying columns and dividing the entries in the bottom row amounts to a change in units and nothing else.

Now look at Figure 6 which was obtained from Figure 5 by dividing the second row by two. Note that the time available on Machine II was also divided by two. This amounts to saying that we have half

I	.99	.909	.97	1.03	25
II	1.02	.918	.99	1.05	17.5
III	.96	.792	.93	1.01	30
	20	25	16	6	
	1	2	3	4	

Figure 6

as many time units available if we use a unit of time twice as large. The entries in Figure 5 might be minutes with 35 minutes available. In Figure 6 the units could be two minute periods and the number of units available for Machine II is 17.5 two minute intervals.

Now we assume that all of the entries in Figure 6 are close enough to unity to approximate Figure 7 in which we see that we require 67 units of machine time and that we have a total of 72.5 units of machine time available. How to solve the "transportation problem" (which is what the array represents) of Figure 7 we shall discuss in connection with the next example.

I	1	1	1	1	25
II	1	1	1	1	17.5
III	1	1	1	1	30
	20	25	16	6	
	1	2	3	4	

Figure 7

Those of you who attempt to solve the original problem in another manner will appreciate the gain in computational efficiency by employing, say, the special method to be presented with the next example. Bear in mind that minimizing a quantity is equivalent to maximizing its negative.

Difference	3	2	4	1	Demand	
Cost	1	4	6	2	8	A
	5	6	2	1	6	B
	4	2	9	7	3	C
Capacity	4	6	4	3		
Factory	I	II	III	IV		

Figure 8

Figure 8 represents the problem confronting a company with four factories and three warehouses. The monthly capacities of the factories and demands of the warehouses are shown. Note the demands just equal the production capacity. The entries in the body of the array show the cost of shipping (could be cost of making and shipping) a unit of product from each factory to each of the warehouses. The problem is to determine the number of units from each factory to ship to each warehouse while minimizing the total cost.

While sets of simultaneous equations can be set up and solved, there is a simple algorithm due to Vogel for solving this type of problem that may work but does not always work. In any case, however, it leads to a practical allocation which is generally not much higher in cost than the minimum possible. The rule is as follows:

Subtract the lowest cost in each column from the second-lowest cost in each column. Then go to the column having the smallest cost difference thus found. Now go to the lowest cost in this column and ship as much as possible from the factory associated with this entry to the warehouse associated with this entry. Adjust the capacities and demands to reflect the assignment and determine the new cost differences as before. Repeat the process.

The first row in Figure 8 shows for each column the differences between the lowest cost and the second lowest cost. We go to column four because the cost difference is smallest. We ship three units from factory IV to warehouse B. This takes all of the capacity of factory IV and hence we delete column four.

Figure 9 is the same as Figure 8 except that we have removed factory IV and have reduced the demand of warehouse B. Column two in Figure 9 now has the smallest difference between the lowest cost and second lowest cost. We ship three units from factory II to warehouse C. We need no longer consider warehouse C.

3	2	4		
1	4	6	8	A
5	6	2	3	B
4	<u>2</u>	9	3	C
4	6	4		
I	II	III		

<u>Figure 9</u>

4	2	4		
1	<u>4</u>	6	8	A
5	6	2	3	B
4	3	4		
I	II	III		

<u>Figure 10</u>

Figure 10 is the same as Figure 9 except that warehouse C has been removed and the remaining capacity of factory II has been indicated. Here we ship the remaining three units from factory II to warehouse A.

Figures 11 and 12 reflect succeeding steps in the process.

4	4	
<u>1</u>	6	5 A
5	2	3 B
4	4	
I	II	

<u>Figure 11</u>

4		
6	1	A
2	3	B
4		
III		

<u>Figure 12</u>

Figure 13 shows the number of units to ship from each factory to each warehouse.

4	3	1	-	8 A
-	-	3	3	6 B
-	3	-	-	3 C
4	6	4	3	
I	II	III	IV	

<u>Figure 13</u>

In solving problems of this type, it may happen as in Figure 11 that more than one column has the smallest cost difference. In this case, choose one of them. That is, frequently there is more than one best shipping pattern although all best ones are equally inexpensive.

Techniques of model approximation are useful in analysis and in planning. A model helps us to understand the effects of the many variables affecting a business. The use of such models has helped in the making up of formula feed for farmers taking into account changing farm prices. Such models have been useful in scheduling of fuel oil shipments. Oil companies do not want to carry high inventories yet they want the probability to be high that they can meet demands in the face of randomly varying weather conditions.

THE SCOPE OF OPERATIONS RESEARCH

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It generally seems appropriate in discussing operations research to produce a definition of this activity. Operations research has often been defined as an activity whose objective is to provide a scientific basis for decision. A definition, once given by an individual who had heard the question bandied about considerably, is that operations research is hard work.

As practiced today, operations research is sometimes concerned with finding the right solution to the right problem. At other times one must be content with trying to provide an understanding of the right problem. This is the case because operations research must be in the framework of the decision-maker; thus, the scope is necessarily broad and the problems correspondingly complex. Today I shall use a few illustrations to try to convey to you some of the thought processes involved in trying to aid a decision-maker.

The Car Replacement Problem

Consider first a problem with which many people are familiar: namely, "When is the best time to buy a new car?" A solution to this problem is to be presented and it is hoped that you will question whether the right problem was worked, whether the facts and assumptions are correct, whether the measure of effectiveness is correct, whether the technique employed in solving the problem is right and whether it provides a sensible basis for decision for anybody.

In Figure 1 is plotted the value of a particular car as a function of time. The upper curve shows the value of a new car, on the assumption that the price rises about $70 per year. The lower curve shows the depreciation of the same car after purchase.

Table I shows the yearly operating and maintenance costs that were assumed. New tires, new brakes and a new battery were installed the third, fifth, and seventh year. The car was

* Presently at the University of Michigan.

CAR VALUES AS A FUNCTION OF TIME

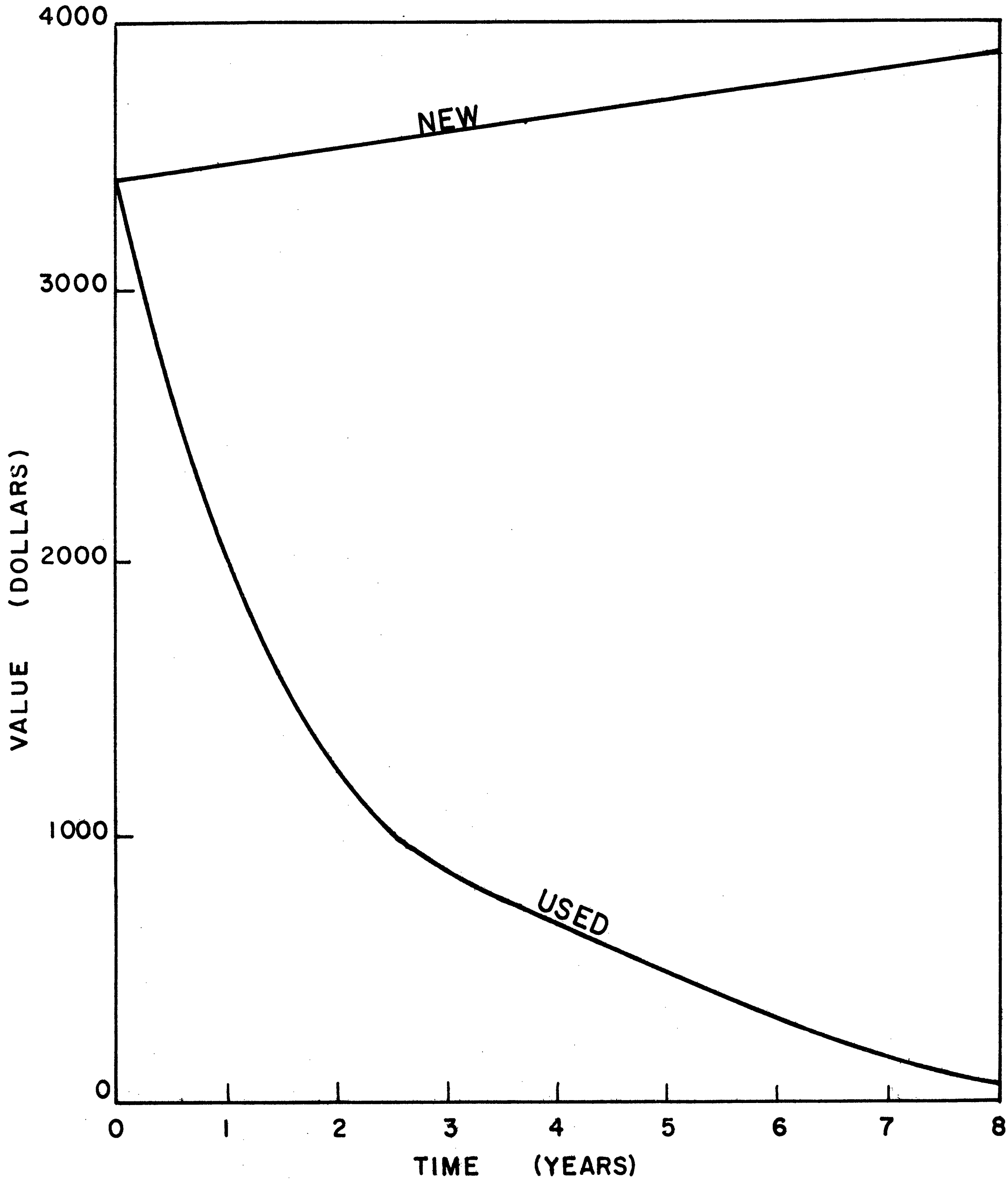


FIGURE I

TABLE I

OPERATING AND MAINTENANCE COST FOR EACH YEAR AFTER PURCHASE

Year	Cost ($)
0	0
1	540
2	570
3	740
4	590
5	740
6	600
7	890
8	640

painted in the sixth year, but it was charged against the seventh year because it was assumed that no on would paint a car in the sixth year and trade it in the sixth year. It was assumed that a car ought to be painted if kept as long as seven years. No major motor overhaul was assumed in the eight-year period considered.

In Figure 2 is presented the cumulative eight-year cost of owning and operating a car if traded in with cash for a new one every year, every two years, etc. This curve takes into consideration the value of the car owned at the end of the eighth year.

It can be concluded from Figure 2 that it makes little difference in the total cost whether the car is traded the fourth to the seventh or eighth year. It must be added that the probability of a major expense becoming necessary at any given time was not included in the analysis. The real question to ask now is whether the information is of use to anyone in deciding when to purchase a new car.

The problem considered is not the right problem for anyone who isn't interested in ever buying a new car. It is the wrong problem for the owner of a fleet of taxis. It is the wrong problem for the fellow for whom the pride of owning a new car is of utmost importance, except that he can obtain some idea of the cost of his vanity.

The assumptions going into the problem defined to some extent the purpose of the car, in that the assumed operating and maintenance costs limit the use of the car. Clearly it would have been more clever to state at the outset what function the car had to perform before working the problem.

Now that some answers are available they may be of some comfort to the owner of a three-year old car who wonders what he has to lose by keeping his car longer. His real concern is whether the monthly repair bills will exceed monthly payments on another car for the next couple of years. He has children to send to college and he simply cannot concern himself about the cumulative cost of owning and operating a car for the next eight years. It makes little sense for him to plan eight years hence.

It is seen from the above discussion that the problem of when to buy a new car has many facets. The right problem varies with the situation. Operations research is like this. Sometimes the right problem is not revealed until some study has gone into the stated problem. For example, some of the fellows at ORO have been studying the problem of information handling. The principal interest

CUMULATIVE 8-YEAR COST OF CAR OWNERSHIP IF TRADED AFTER THE END OF THE YEAR SHOWN

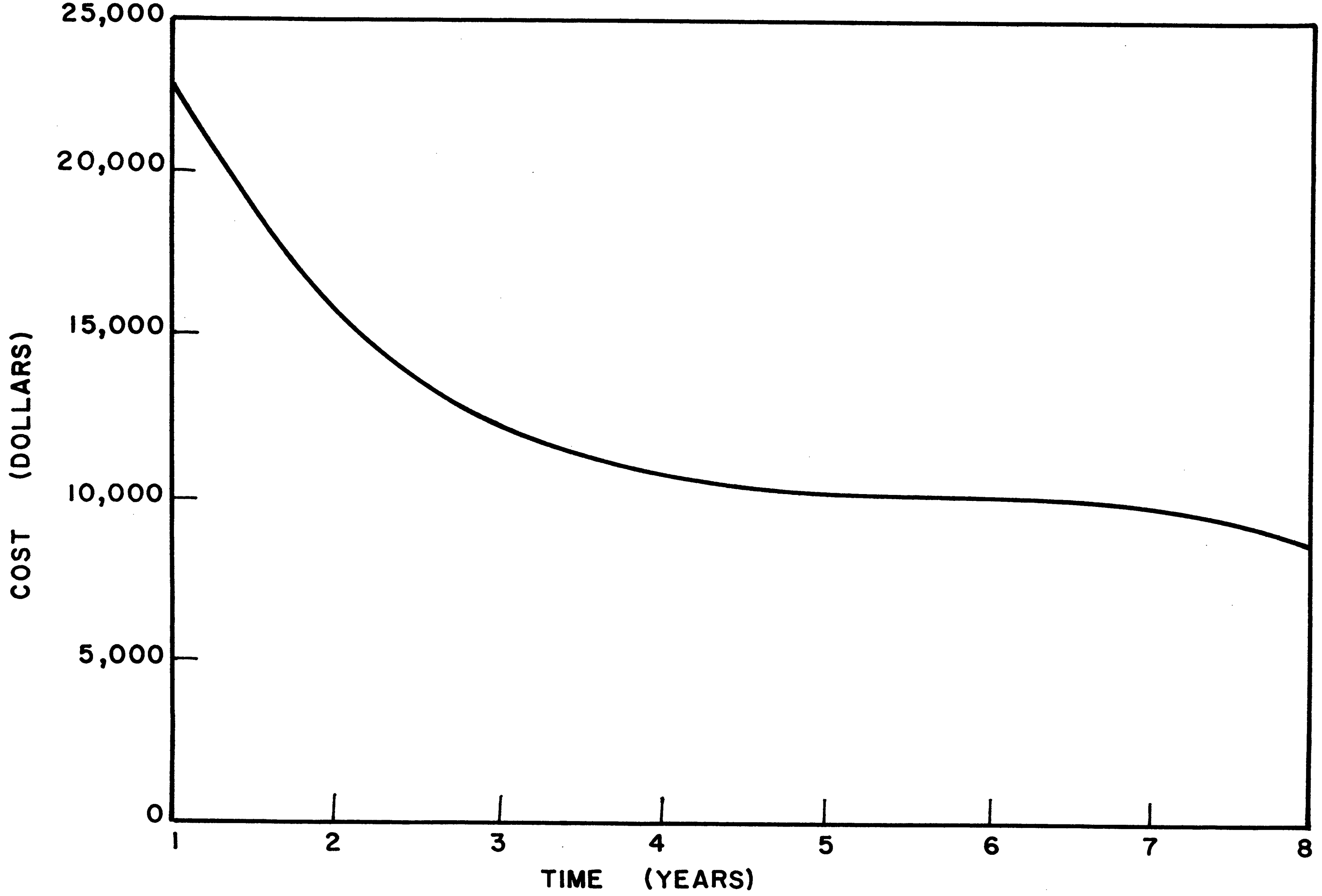


FIGURE 2

has been in field army communications, but as many people know, it is very difficult to learn much from maneuvers and the historical records do not contain much information that is useful for such studies. Accordingly, it appeared worthwhile to get one's "feet wet" by working with an operating organization. Recently the opportunity arose to study a real operation with real data in cooperation with ACAN (Army Command and Administration Network, the world-wide communication net of the Army).

Communications System

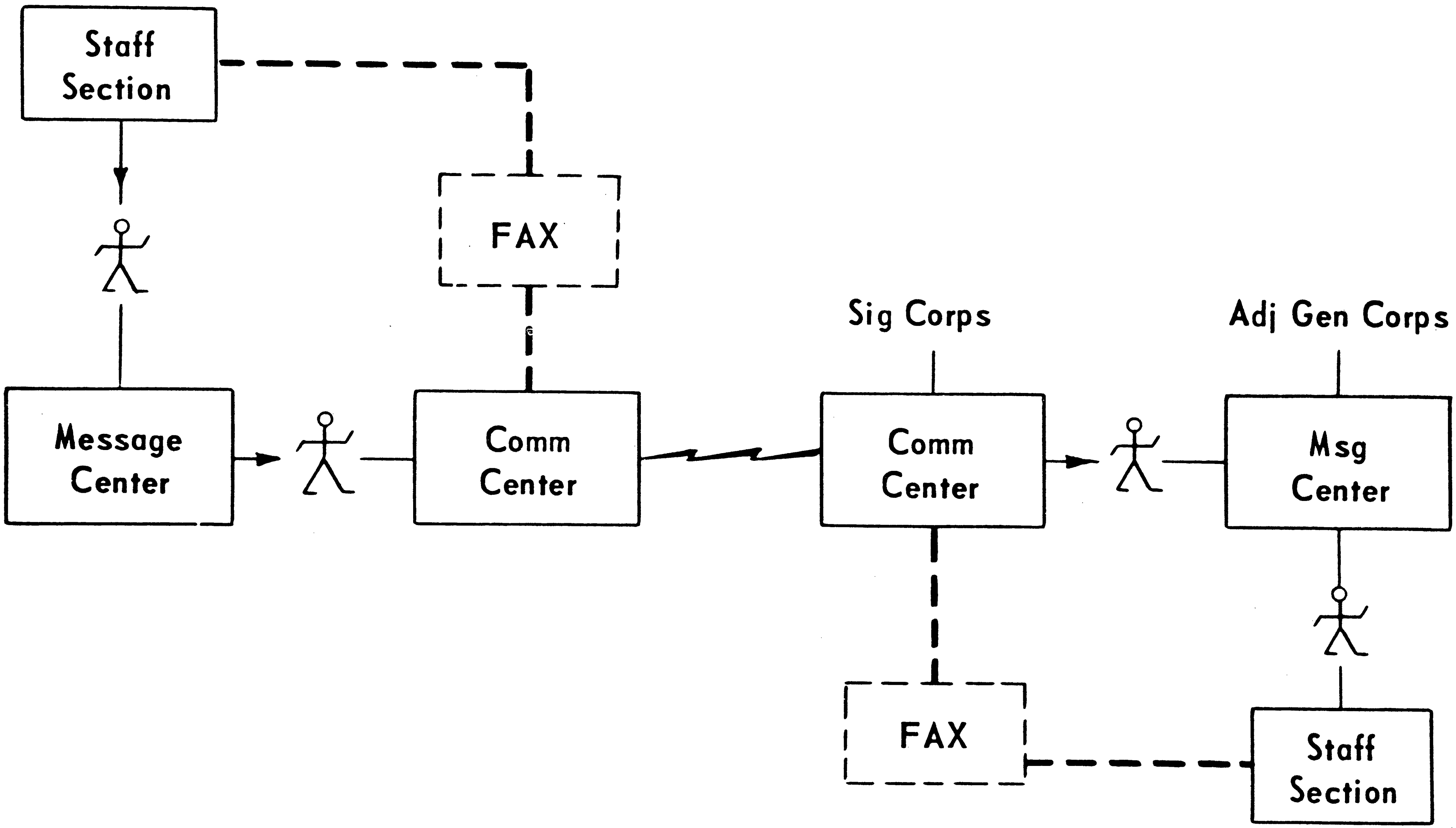
The Signal Corps and the Adjutant General Corps (AG) have a combined responsibility to provide the Army with the capability for rapid and accurate communication. In the fixed communication system the Signal function (for electrical communications) begins with the time of receipt in the Communication Center at the originating headquarters and ends with the time the transmitted message leaves the Terminal Section of the Communication Center at the receiving station. Chargeable to over-all communication time are two other increments composing the AG function: to effect proper control and release of traffic at the point of origin and to maintain adequate records and message delivery service at the destination, the AG operates Message Centers within each headquarters. The total communication time then must include time of administration processing at both ends of the message route.

Figure 3 illustrates the part of the communication net of concern. Messages originating in some staff section are collected by a messenger and delivered to the Message Center, operated by the AG. From the Message Center the message is delivered to the Communication Center by a second messenger. The message is then transmitted to the receiving communication center, delivered to its Message Center by a messenger, processed and finally delivered by another messenger to a receiving staff section.

The teletype traffic flow chart in Figure 4 illustrates some of the details of the processing that takes place in a Message Center on incoming and outgoing traffic.

Prior to the time ORO entered the picture, unsatisfactory attempts had been made to determine the effect on average message delay times of introducing facsimile (FAX) into the positions shown by dotted lines in Figure 3 in hopes that action copies might reach the proper addressees more rapidly than by going through the normal

Fig. 3—Communication Net.



TELETYPE TRAFFIC FLOW CHART

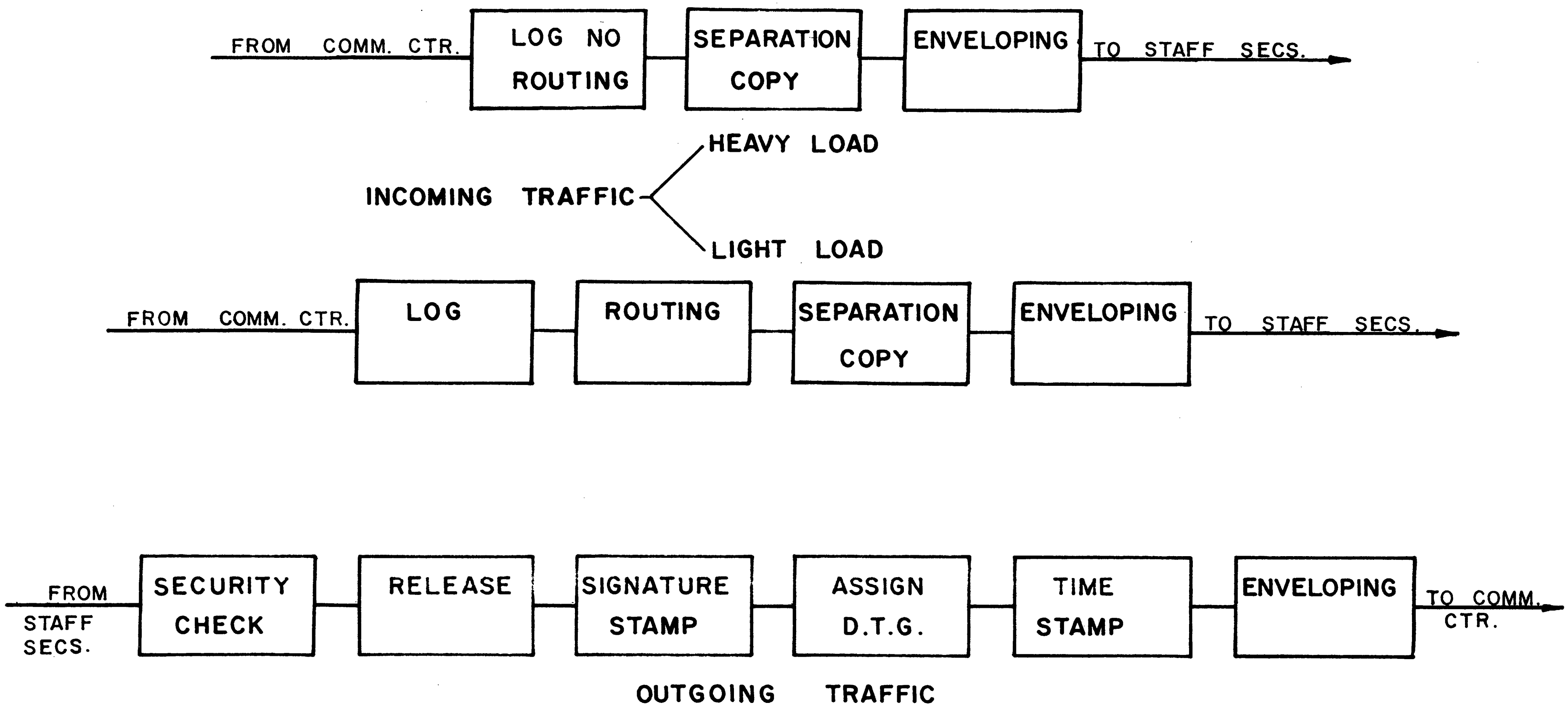


FIGURE 4

channels. The original problem on which ORO expected to work was that of determining the usefulness of facsimile in minimizing delays in this system.

A three-day conference was held to discuss the proposed experiment to be conducted at Headquarters First Army. The conclusion of the conference was that insufficient basic data were available to justify the experiment.

Accordingly in cooperation with the AG and Signal staffs at First Army, a two-week test was set up to record the appropriate data in the actual operating agency. A most surprising result came from the analysis of the data at ORO: namely, responsibility for the large delays computed for Message Center processing may be ascribed to messenger scheduling of deliveries from Communication to Message Center and from Message Center to receiving staff sections. Delays could vary as much as perhaps 50% depending on the staggering of the schedules of messengers indicated in Figure 3. On the receiving end, for example, the first messenger picks up a stack of messages at the Communication Center and delivers them to the Message Center where they are processed. They are picked up by the second messenger on schedule and distributed to the addressees. It is obvious, after the fact, that these messengers complicate what otherwise appears to be a neat queueing problem and that their schedule can play an important role in the average delay times.

The nature of the rules governing the messengers is such that existing queueing theory is inadequate for finding the best way to schedule the messengers. ORO's simple physical simulator, named the Queueiac, made possible a one-to-one analogy to the actual problem, and produced the solution.

The moral of this tale is clear. Persons with insight looked at a real problem--redefined it, and found a way to make a substantial improvement without the user having to spend any additional money. It would have been easy and natural to flounder around for a long time with the original problem.

<u>Negative Decision</u>

ORO was recently asked to recommend how many of a new device should be procured and how many needed to be allocated where. The recommendation following that study was simple, don't buy any, they are relatively useless. Here the true purpose of the device was examined, and the device was found wanting. This single study should result in the saving of enough money to pay ORO's expenses for many years.

Now these have been examples of finding the right solution to the right problem.

Pay-off from Advertising

Now let us illustrate with another example another facet of operations research, that of trying to understand the right problem. Consider a purely hypothetical problem having to do with advertising. How much effort should be expended in producing an advertisement? Here it is assumed that the advertisement will be distributed to the recipient with the hopes that he will make a purchase and possibly become a steady customer.

For the purpose of simplicity only two parameters will be considered in this problem (although others could be added at will): production effort and distribution effort. Distribution could take many forms, from handbills to TV.

Figure 5 shows a synthetic plot of the probability of success vs. production effort. As is the case with many activities some effort is required before there is any pay-off, so the curve intercepts the horizontal axis at some point on the positive side of zero.

The general shape of the curve is correct, for there are enough suckers in the world to make the rapid rise in the curve plausible. Also, there are enough stubborn people to make the achievement of 100% success very difficult, if not impossible.

An examination of Figure 5 makes it clear that, when considering production effort alone, it is easy to determine what effort will be expended to achieve a given probability of success. There are just four items, however, that are critical about this curve: (1) What is 100% success?; (2) How is effort measured?; (3) What data provide the relationship between effort and probability of success?; and (4) What is a sensible probability of success to require?

That such questions must be given careful consideration is indicative of the fact that operations research, directed toward aiding in the decision process, is much broader in scope than ordinary trouble shooting.

PROBABILITY OF SUCCESS vs PRODUCTION EFFORT

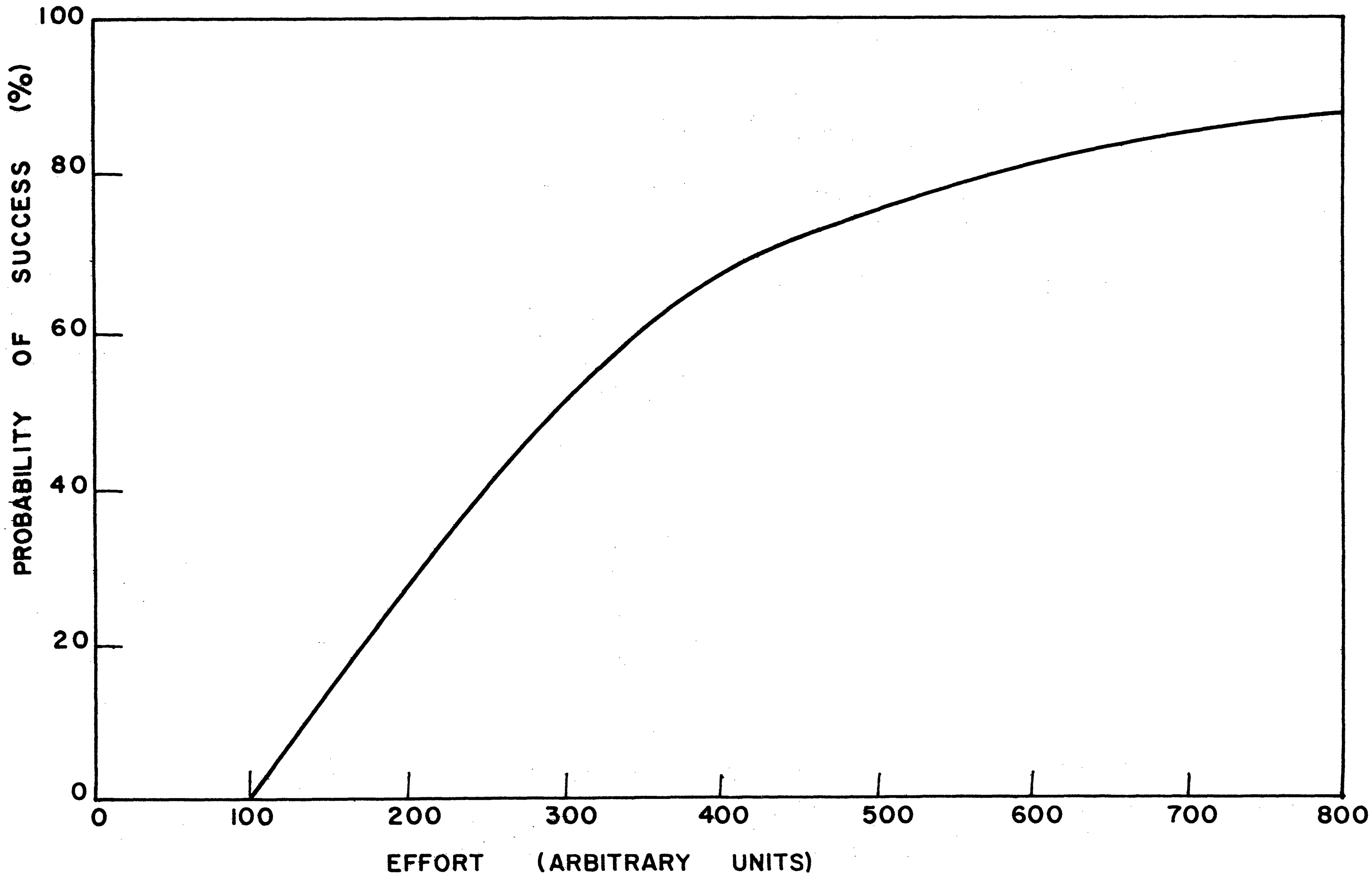


FIGURE 5

These four questions, are, in my opinion, the crucial questions in operations research. The answer to them determines the anwer to any problem undertaken. The technique used and the labor involved are relatively incidental. If command decision is resorted to in answering any of the four questions, the solution to the problem is achieved by command decision. This may not of necessity be bad, but it is true, and should be recognized by all concerned.

For the purpose of discussion assume that only the last of the four questions is unresolved. In Figure 6 is plotted the probability of success vs. total effort; in this case production plus distribution effort. Four curves are plotted: Curve A corresponds to a distribution effort equal to zero, Curves B, C, and D corresponding to distribution efforts of 100, 200, and 400 units, respectively.

If a fixed probability of success is chosen, it is easy to see how fast the total effort required changes as the distribution effort is increased. Furthermore, given a fixed total effort, the probability of success falls rapidly as the distribution effort increases. It is clearly difficult to decide what probability of success is a reasonable one to select. The advertising manager may have a reasonable basis for decision from his point of view, for he is likely to be forced to operate within a fixed budget. His budget may not, however, have been determined on a rational basis, so it is not easy to justify the selection of a particular point on the curve.

There is one possible criterion for decision to consider which may have merit; namely, to ask that the ratio of the probability of success to total effort be a maximum. This ratio is a maximum at the point where a line drawn through the origin is tangent to the curve in question. These tangents are shown in Figure 6. The points of tangency define the optimum probability of success to specify; i.e., optimum if the criterion as to what is best is accepted.

From Figure 6 the data were obtained for Figure 7 where the optimum production vs. distribution effort is shown. It is interesting to note that the optimum production effort does not vary a great deal, even though the distribution effort varies by a large factor. This is a rather comforting result which was not obvious at the outset, for it is seen that a reasonable choice of the effort that goes into production can be made even though the production costs are not known within a factor of two or more.

PROBABILITY OF SUCCESS vs PRODUCTION PLUS DISTRIBUTION EFFORT

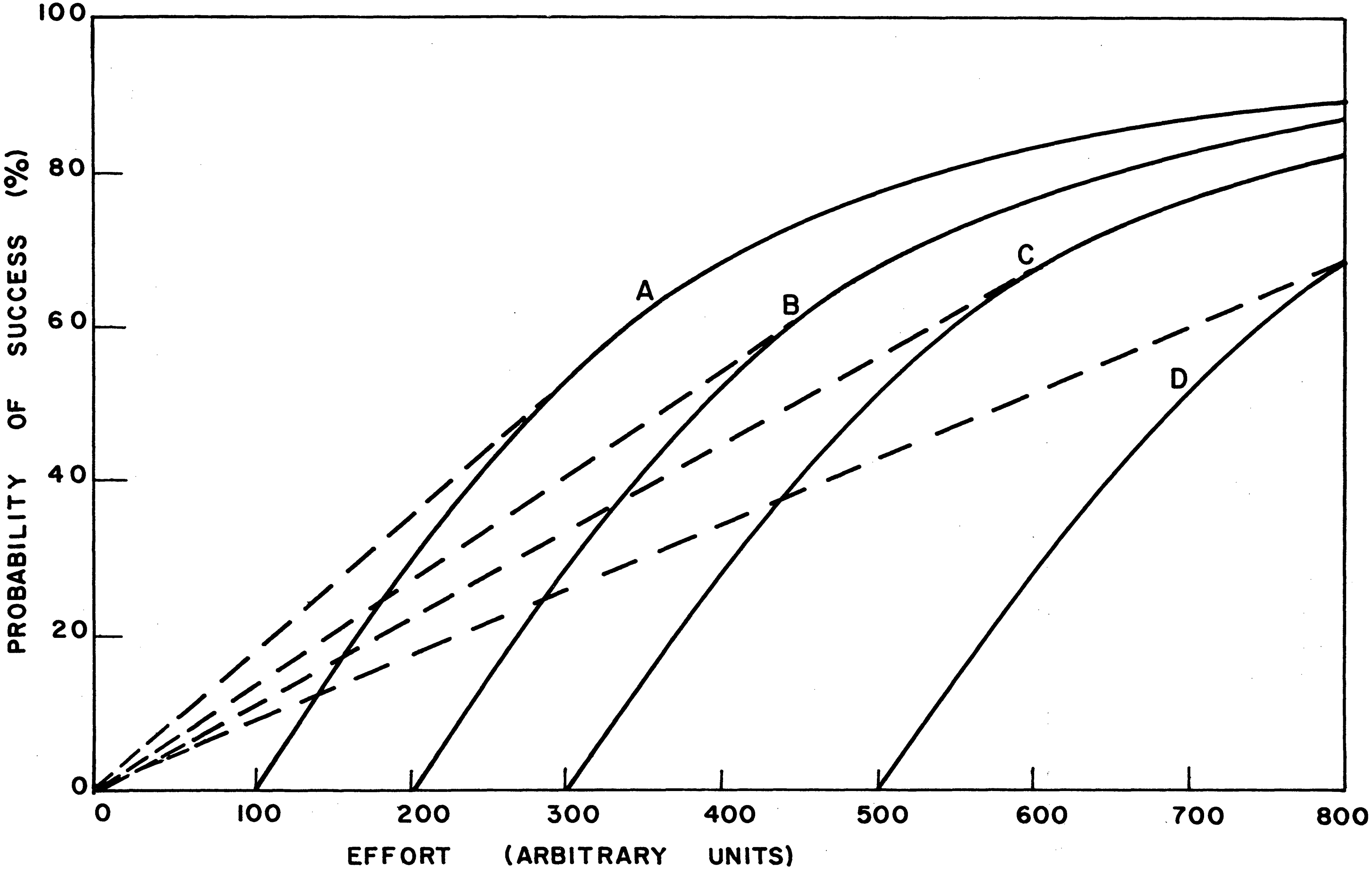


FIGURE 6

OPTIMUM PRODUCTION EFFORT vs DISTRIBUTION EFFORT

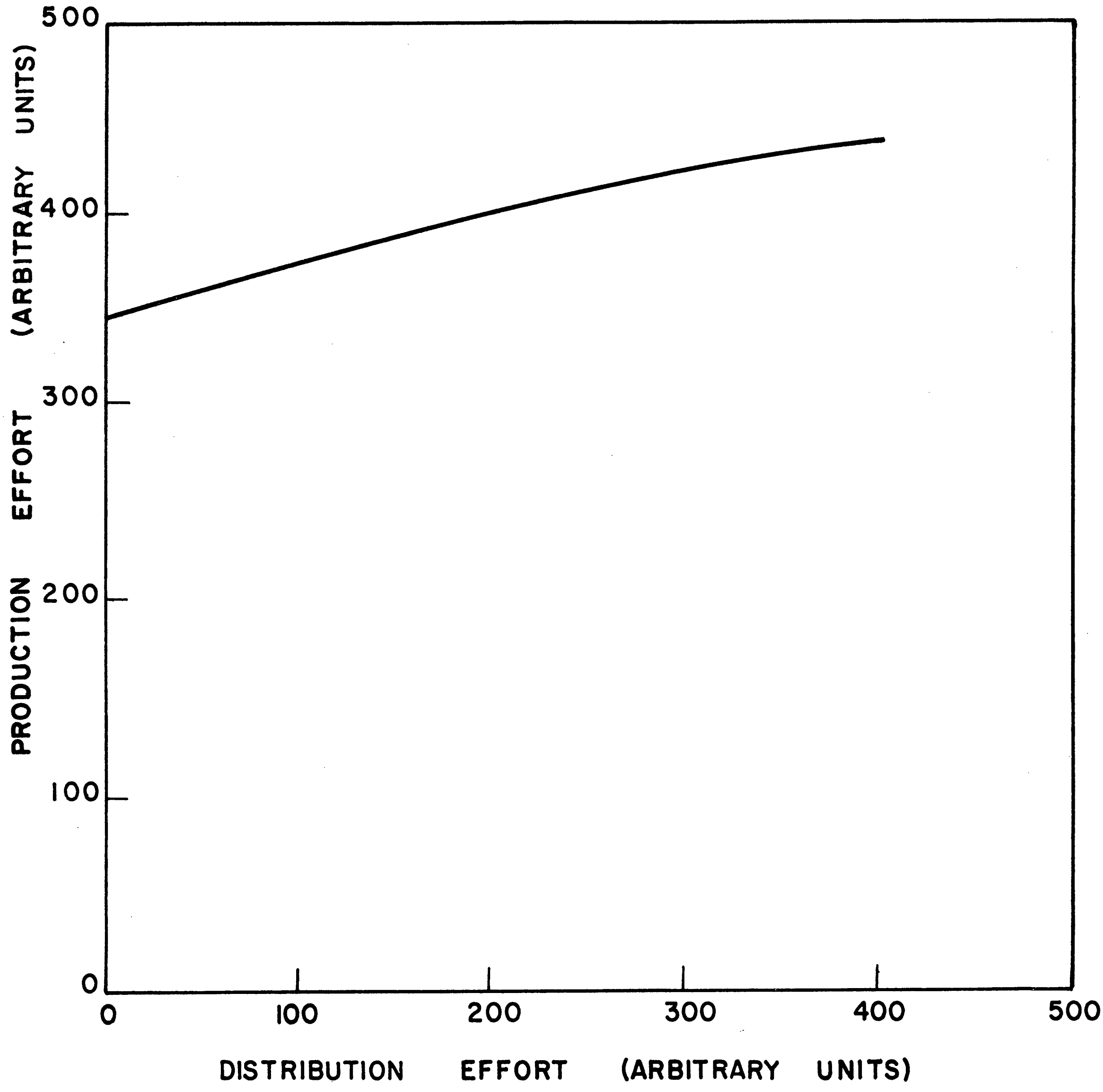


FIGURE 7

In this problem there is no question but that the objective is to convince a potential customer. There is no question but that the impact of the advertisement itself convinces the customer. It therefore seems reasonable to suggest that the production effort is a crucial parameter in the problem. One medium of distribution may be superior to another and is a parameter that would doubtless have to be considered in a real advertisement problem, but once a medium is selected the technique illustrated does indicate that the optimum production effort is relatively insensitive to the distribution effort.

It can easily happen in applying the above type of criterion to a problem that the optimum probability of success will turn out to be only, say, 30%. If such is the case, the natural reaction is that the result is unacceptable. If such is the case, it is possible that the decision as to what is meant by 100% is unacceptable and should be reviewed. It might also be argued that the application of the criterion of optimizing the ratio of the probability of success to effort is nonsense.

The point of this whole discussion is that it is of utmost importance to find some sensible way of defining success. It is often impossible to guarantee 100% success because many probabilistic events may influence the chances of being 100% successful. It is therefore necessary to search for reasonable criteria for setting practicable goals. One such criterion has been presented in the advertising problem for the purpose of illustrating the importance of the initial decisions on the outcome of a problem. This criterion has the interesting property that one crucial decision is the result of an analysis, not an input. Other criteria, such as maximizing gain or minimizing loss, might of course have been considered.

Now some problems can become bulky if not complicated, bulky as regards the number of computations required in order to arrive at a solution. In dealing with an operating system, it is frequently possible to measure unknown quantities and count items. Such problems can be solved with the aid of modern computers. With future systems with no data, or at best sketchy data, one can only examine how the system may operate as the quantities which are critical to the operation are varied over reasonable limits. These can become unwieldy, however, for if the system has, say, 10 variables and each variable is allowed to take on 5 values, there are 5^{10} individual cases to examine. And imagine the intuition required to determine if the range of values investigated is indeed reasonable!

Life in operations research can certainly become complex when the performance of unknown equipment in a non-existent organization is contemplated. The fact is, then, that some current work in operations research is not producing clean-cut quantitative solutions to well-defined problems. It must be realized that the effort is being expended in hopes of obtaining a better understanding of complex questions on which decisions are being made all too often. Such work is justified by faith in the notion that better decisions can be made if the problem is comprehended than otherwise.

The value of physical and mathematical models has been known for years. Their value is becoming more appreciated as one attempts to examine little understood operational problems. Simulation, however simple or complex, offers a powerful tool for understanding. Many existing organizations and operating procedures have evolved through a process of trial and error. Such an evolutionary process is naturally slow and costly. In contemplating new organizations and operations, mathematical models are very useful. Frequently, however, the models are inadequate or they become intractable. In such cases simulation provides a compromise between a pure mathematical approach and the trial and error method of evolution--this latter method being impossible with non-existing organizations.

We have at ORO an 1103 computer, but when we decided it would be necessary to simulate some message handling and organizational problems, we decided to build a simple physical analog with extremely limited capacity so we could begin to understand the problem. Reference was made earlier to the work on delay times with the First Army. When the proposed test of facsimile was first considered, it was expected that it would be possible simply to examine existing records, acquire the appropriate data and run the test on the Queueiac. When it was ascertained that there wasn't even enough operational data available to fill up our eight channels on the machine, we were fairly sure that our decision to stay away from the high-speed computer was right. When the real problem was uncovered, the right data obtained, and the solution to at least a part of the optimum messenger schedule obtained, we were confident we had made the right decision. The scale of this computer can be visualized by examining Figure 8. The Queueiac is described in detail in an article by Dunn, Flagle and Hicks in the December 1956 issue of JORSA.

The Queueiac is at the same time a one-to-one analog of certain kinds of situations, a display unit and a low-speed digital

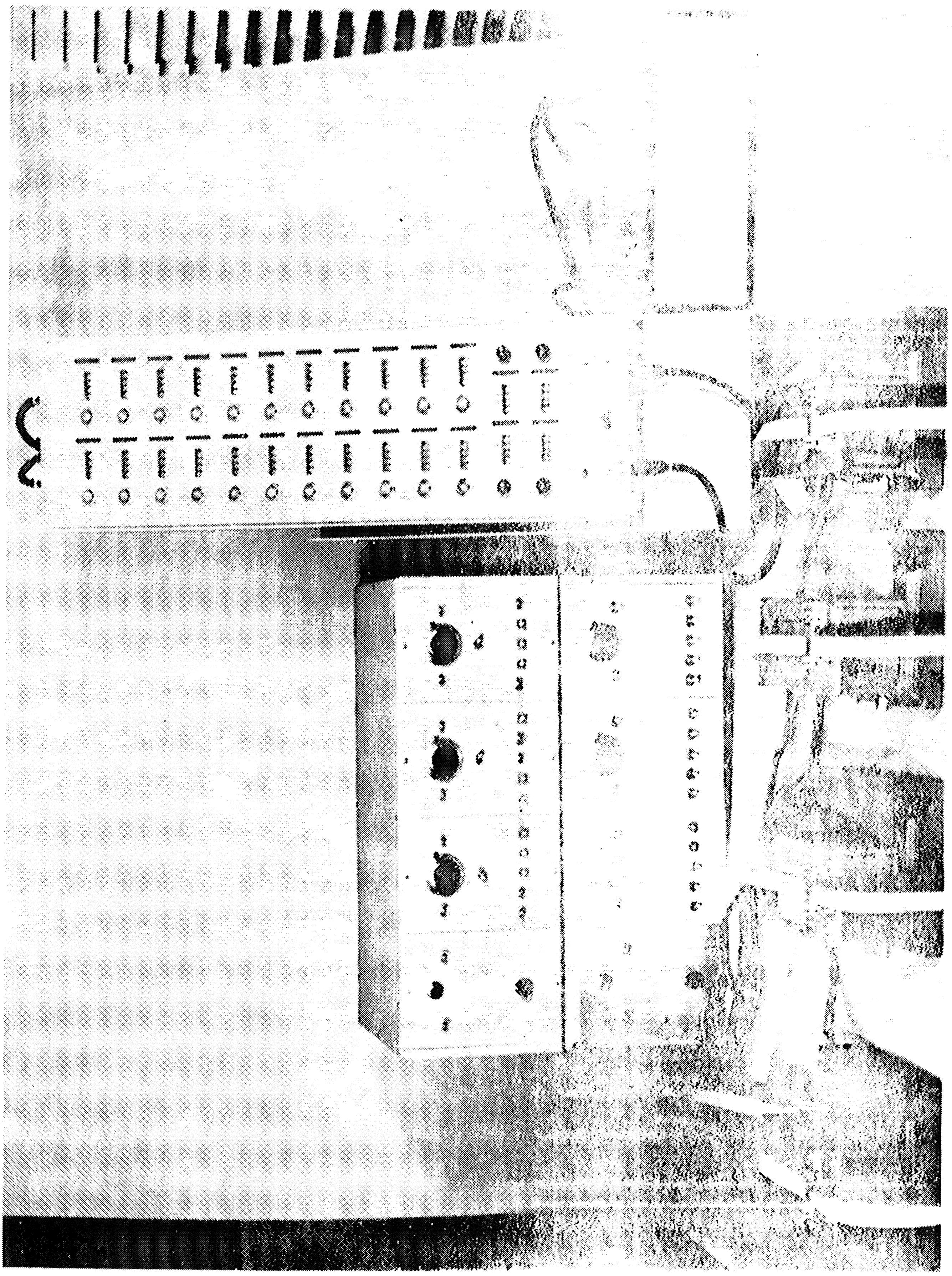


FIGURE 8

computer. It serves as an illustration of the value of simulation on a small scale. It serves to give confidence in one's ability to comprehend and simulate much more complex problems and organizations. Simulation seems ideal for planning field experiments, and it is, of course, less embarrassing to make a stupid mistake in the laboratory rather than in front of a couple of battalions. I well remember the first time I had a division of destroyers on a field test in 1942 when I found there were many things I wished I had anticipated beforehand. Well do I remember our first experience with a model we built of our magnetic shipborne submarine detector to use as a trainer for officers. We learned more from that model in a few days than we had learned working on shipboard in our first six months. Had the model been made in the beginning, the work would have progressed much more rapidly than it actually did.

High-speed computers are busy 24 hours a day doing detailed computations on complex problems. They are being tied in with people involved in war gaming activities on problems too involved to visualize otherwise. The least that can be said for gaming activities where there is a model of a game, rules, players, and a referee is that one's understanding is growing by leaps and bounds. It is true that a game is fundamentally no better than the model, the rules, and the input factors. It is true that an outsider can sometimes come into a gaming group and find a glaring fallacy.

Nevertheless, gaming is paying dividends in understanding and frequently in producing real answers--sometimes when least expected. It is providing a means for testing the feasibility of concepts that otherwise cannot be tested.

It is hoped that with this brief presentation, it has been possible to illustrate that operations research, as now practiced, is an activity whose objective is sometimes a search for the right solution to the right problem and sometimes a search for an understanding of the right problem. Perhaps by examining some of the thought processes it has been possible to convey an idea of the scope of the effort. Definitely, operations research is hard work.

COST ACCOUNTING AND OPERATIONS RESEARCH*

C. W. Churchman
Case Institute of Technology

Previous speakers before your seminar have probably given many definitions of operations research (OR) because there are various ways of looking at it. I came to OR through philosophy, and I look at it from the point of view of the philosopher. Your last speaker, Professor Charnes, no doubt looks at OR as mathematics. It is right that a field as rich as OR should have a number of ways it can be looked at.

Definition of Operations Research

It is difficult to say what OR is if your listener insists on separating judgment from science. Actually OR is organized judgment. Operations research will not supplant executive judgment. It opens new areas for executive judgment and provides new aids for checking judgments. This is the main point I will make. Let me illustrate by bringing up the central problem in operations research. How do we get the data for the mathematical models? In particular, how do we get cost data? I will discuss in some detail the OR view of costs and managerial decision making involving costs. We are accustomed to thinking of costs as "facts" but the only source of facts is good judgment.

The word "science" surrounds operations research. We talk of the scientific method in OR. What is science? I won't lecture on this subject, but there is a way of looking at science I will mention. Science is a way of cross-checking judgments. The amazing thing about science is that outsiders come into a field and make the same judgments as those who have gone before. Laboratory measurements are judgments, as any one of you with laboratory experience will admit. Science is great because of the many cross-checks on the judgment of observers, not because of the observers.

The methods of science are not very different from those of the executive. Any organization has executives making judgments. Others judge what a particular executive has said. If the executive's

* Notes taken by J. Hoagbin

judgments do not cross-check, one of two things happens: the executive is removed or the inconsistencies are removed. Science also tries to minimize inconsistent judgment. Operations research shows the way to cross-check and better coordinate the judgments of executives. In what way does it coordinate? The answer is that cross-checks and coordination come from the effort in OR to formulate problems mathematically.

Value of Mathematical Formulation

The last decade has seen considerable effort devoted to the "modeling" of systems. I will give two examples of the type of problem that has been thoroughly studied.

The first example is the "reorder problem". When it is necessary in a business to reorder, what are the quantities to reorder? The first work on this problem was done 40 years ago but the last ten years has seen enormous development. In the simplest statement of this problem we have one man who must reorder the proper amount of a particular item at a certain point in time. For example, the corner grocer finds his shelves almost bare of peanut butter.

What help can be expected from attempting to make this problem quantitative or attempting to write down a formula? If the grocer is in business for profit, he no doubt wants to provide peanut butter for his customers at minimum cost to himself. That is, it seems reasonable for him to desire to make the sum of the following costs a minimum:

1) The cost of placing an order, which will influence how frequently he orders.

2) The cost of being out of peanut butter. That is, the cost in goodwill and future sales when a customer can't buy peanut butter in his store.

3) The cost of carrying unsold peanut butter in inventory. That is, the cost of breakage, spoilage, and the reduced sales of other groceries that could be displayed and stored in the space occupied by the peanut butter.

One can think of ways of solving the reorder problem without taking into account these costs, but no other way seems adequate. <u>The value of a formula relating these costs is that it constitutes a list of just those costs or judgments that are important</u>. Those that are not important are eliminated. <u>Also a formula shows clearly the relative importance of the costs</u>.

A second example involves "waiting line theory" or "queueing theory". The potential here is enormous. It is possible to get satisfactory closed solutions to practical problems involving queueing theory through using an approximation based on reduction to a single department and proceeding in such a way as not to disturb the operations of the rest of the business. If industry were better acquainted with queueing theory there would be many more applications. The theory applies to such problems as the number of mechanics required in a repair unit. It shows the relationship between the input function and the service function in which the basic elements are:

1) How much waiting time is permissible?

2) How many service units should there be?

One of the projects at Case Institute involved the operations of a company making parts for auto manufacturers. Material went through the following stages:

1) Raw Material

2) Casting

3) Storage

4) Fabrication

5) Storage until required by customers.

The company had adopted policies that tended to reduce inventory. That is, the company attempted to keep few of the finished parts on hand and few castings and stampings in storage. This policy implied long lead times for processing an order.

Here was clearly a queueing theory peoblem but many operations are performed on each part in this company and the whole problem is too complicated for the mathematics now available. However, it was possible to tackle parts of the business. That is, it was possible to consider the fabrication departments and their inputs and outputs as a separate problem. Here fabrication was considered to be the "customer" for the items in storage and in process. The study was able to show clearly to management the relationship between:

1) The cost of a delay in supplying a customer.

2) The cost of carrying too many finished parts.

Management, armed with the results, increased the amount of material "in process" and in inventory. As in all such studies, management made the final decisions.

Why Aren't Costs Available?

In OR the definition of cost is more closely allied to the definition in economics than in accounting. That is costs are allied with opportunity costs rather than the accountant's figures. Costs are sacrificed values. Let me illustrate this:

A decision maker is ordinarily confronted with a set of alternative actions and a set of desirable outcomes. He has a problem only because there is no single action or set of actions that will lead to attaining all of the desirable outcomes. The executive is under pressure to make the right decision but there is no single best action. In the example we discussed above, the company desired to cut delays and carry no inventory. But there is no way both objectives can be achieved. The company must sacrifice one or both. Costs are the extent to which one is willing to sacrifice a goal. Costs measure the degree of the sacrifice in realizing an objective. This is what the economist calls opportunity costs.

It is amazing that 90 percent of the work in OR is the gathering of cost information. Not just for new businesses, but for old businesses as well, the really important cost information does not exist. For example, any outsider can see immediately that the data most relevant to running a railroad aren't collected. Railroads don't know the relative costs of hauling different commodities. Railroads have never even determined how long a train should be. Should a train be 200 cars long or 40 cars long? Some work would be required to get this information, but the problem itself is not complicated. It is positively amazing that railroads have never gathered the data necessary to answer such questions.

In another study at Case Institute, the problem was to determine the cost of set-up for various operations for a large machine tool manufacturer. It was found that this data did not exist and what passed for these "costs" weren't collected in the right form. Why weren't they? Why don't companies collect data relevant to making judgments? Analysis of the problem indicates that there are basic data that has never been collected. Why?

One possible answer is that the relevant data are not available in the usual accounting records. These costs can't be tacked on like overhead and depreciation. These costs are too far from bookkeeping to make such a simple gimick work. The costs we want are matters of judgment.

This is probably not a very good answer. Even the accounting figures are matters of judgment except, possibly, cash on hand. If you look at the items on a balance sheet you will see that most of them are matters of judgment.

A second possible answer is that people up to now have not found ways to analyze these problems. This is not a good answer because experience has shown that it is possible to minimize costs.

I honestly don't know why the proper data aren't collected. I will leave you with this mystery. Why is it businesses don't know the cost of carrying an asset such as cash on hand or the cost of maintaining an inventory including the cost of deterioration, of obsolescence and tied-up funds? The size of the asset in a balance sheet is not a good indication of the cost of carrying an asset. The cost of carrying cash is the cost of tied-up capital. The cost of carrying an inventory is more than a percentage value of the inventory based on tied-up capital; it includes obsolescence, losses, etc.

Regarding time delays and lead times, I don't know of a single company that collects the proper data on the total time required to process products. It is impossible to state whether cutting delays from 90 to 60 days is worthwhile.

Setup costs are not known. When such costs are known, they usually include overhead, which may not be relevant to managerial decision making. Setup costs involve the size of the run, the cost of getting set up, the cost of running, and the cost of holding some parts in inventory. Burden has little to do with the problem of the optimum number of setups.

Consider breakdown costs. Except for the cost of capital replacement, these costs are also not available. Yet every company should know the cost of a breakdown and the cost of not servicing a unit immediately.

Operations research has shown that these costs do exist whether we like it or not. Management has to make these judgements implicitly if not explicitly. In fact, one can determine, in a particular operation, how much management implicitly thought these costs were. In the reorder problem one can set up the mathematical model and determine from existing policy what management thinks is the cost of a shortage. By looking at the operations of airlines one can tell what they think is the cost of an accident or a lost life. Airlines realize they can't afford to spend an infinite amount of money to prevent accidents and loss of life. They must make some judgments about the value of the life and the value of preventing an accident. They have made these judgments. They might as well know what they are.

Costs Can Be Obtained

We have already seen that facts are judgments. The "fact" that there are nine planets in the solar system is just a best educated judgment. It is a decision just as all judgments are decisions. Judgments become better as we compare them and integrate them with other judgments. In science the system of judgment making is highly developed. Cash on hand seems to be a fact because it is easily confirmed. The cost of a shortage is not so easily confirmed. Yet the cost of a shortage is just as important as cash on hand so one must use the best estimate he has available.

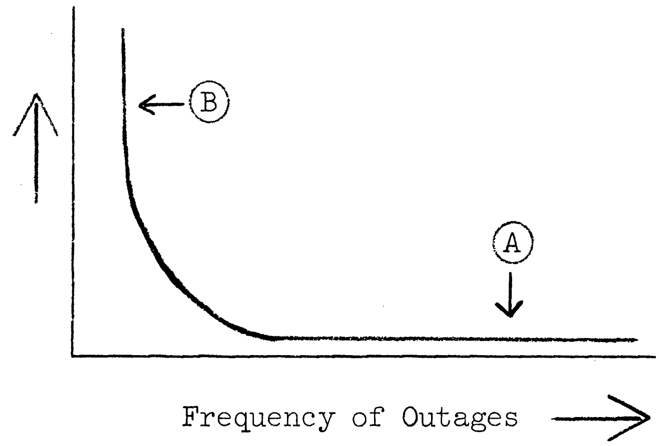
The cost of an accident on an airline is there even though we don't like to talk about it. There are various places in an airline system where something unfortunate might happen. One must consider the cost of prevention of an unfortunate occurrence and the cost of the occurrence.

One of our projects concerned a burglar alarm system for business places. The entry of a burglar rings an alarm at a central office from which a guard is dispatched. It was found that 95 percent of the signals were caused by cats or winds and not by burglars. Here the cost of the occurrence of an unfortunate event could be obtained because one could determine the cost of dispatching the guard. It was necessary to determine the cost of preventing an occurrence: The cost of better educating the users of the service and the cost of better materials were considered, for example.

Another Case Institute study involved the problem of a public utility. The problem was how much generator capacity to have in order to reduce the probability of an outage of electric power. It is not easy to determine the cost of an outage in view of the large number and variety of customers. Estimates of this cost were obtained by conversations with power company executives.

An oversimplified example of how the cost of an outage can be determined by negotiation with executives follows:

Study will result in a knowledge of the relationship between frequency of occurrence of outages and the cost of prevention (cost of generator capacity). Executives can be shown this relationship in a graph such as that in the figure just below.



The executives are asked to pick a desirable operating point on the graph. If a point near A in the figure is chosen, the judged cost of an outage must be small since from the graph it can be seen that a small expenditure would greatly reduce the number of occurrences. Note that in the region of B large amounts of money are required to reduce the frequency of occurrence. After an operating point is chosen one can find from the graph what it would cost to reduce the expected frequency of occurrence of outages. Such methods can be used in consideration of the costs of an accident. The choice of an operating point on the graph is tantamount to judging the value of preventing an accident, i.e., the cost of an accident.

In another study we considered the cost of each minute of delay in answering a service call.

Experience showed that this company for some time had been answering calls within 45 minutes on the average. But should the average delay be 40 minutes or 50 minutes instead? I mention this case because we were able to determine from records what the company thought was the value of reducing the average delay time one minute. Records showed that on three separate occasions the company had added service facilities when the average time delay in answering service calls crept above the traditional 45 minutes. On each occasion enough facilities were added to bring the average back to about 45 minutes. It was determined from the money spent on increased facilities and from the reduction in delays resulting that the company was willing to spend approximately the same amount of money to reduce the average delay time by one minute. The interesting thing is that these implicit judgments on the three separate occasions were consistent since all three were in the neighborhood of the same value of the dollar per minute of delay.

We have been considering cases where an attempt was made to reduce the sum of the cost of prevention and the cost of an unfortunate occurrence. That is the sum of

$$C_p + C_o$$

where C_p is the cost of preventing an occurrence while C_o is the cost of an average unfortunate occurrence.

Estimating the cost of an unfortunate event is sometimes awkward and can sometimes be eliminated by considering instead a cost of expediting. That is, there are certain unfortunate events which are heralded by some signal. Frequently there is some emergency action that can be taken to prevent the occurrence of the event. An airline, for example, might consider unfortunate the cancellation of a flight because of a sick pilot or hostess. The cost of a cancellation is difficult to estimate and is certainly more than the dollars and cents involved in the loss of fares for the trip. However, the airline may prevent the occurrence of such unfortunate events by arranging to have substitute pilots or hostesses flown in as soon as they learn of the sickness of a regular crew member. The cost of taking such actions can be more readily estimated than the cost of the unfortunate event. Thus we can consider the problem of minimizing the sum of

$$C_p + C_e$$

where C_e is the cost of expediting. In other words, C_o does not occur in the final formulation of the problem.

I know of a drug firm that receives frequent emergency orders. They place a very high value on the cost of a failure to fill one of them. When an emergency order arrives they shut down some of their regular activities and disrupt normal routines considerably in order to fill the order. The cost of expediting can be determined and the need for estimating the cost of failure to fulfill an emergency order is avoided.

It is possible to develop a system for cross checking judgments. As indicated in the example of the power company, we may not have to be as hazy as we think.

Some of the most important areas of management have not yet been investigated, and some of the most important problems have not yet been solved. It is worth a great deal to do anything that will increase management know-how. Perhaps some of the hesitation in studying management problems comes about because of a fear of using subjective judgments of the relevant cost data. I have been arguing that this fear is groundless provided some judgments can be used to check others. The mathematical model of a system reveals how such cross checks can be made.

THE APPLICATION OF THE SYSTEM DESIGN PROCESS TO BUSINESS PROBLEMS*

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University of Michigan

The time available will not allow me to explore fully the subject of this talk. I will confine my remarks to business data processing problems although what I say will be applicable to other problems. I will convey to you a few notions I have worked out as a result of experience in the design of large systems. It is not immediately apparent that military and business systems are similar but they have certain common characteristics. Actually, problems concerned with widely different systems are quite similar.

I will try to show that the rate at which we live is increasing exponentially. This gives rise to new problems. The new problem areas have certain common characteristics that affect the solutions. The business data processing has these characteristics. Therefore its solutions should look like those in other systems. I will also discuss a process for the design of solutions.

Increase in Complexity

Let me explain what I mean by the exponentially increasing rate of living. First of all the number of people and the number of contacts with people is increasing exponentially. The table just below shows how the world population has increased in 200 years:

Date	Population
1750	800 million
1850	1200 million
1950	2400 million

The rate of increase of contacts between people can be demonstrated by the table just below showing the percent of the total population in this country living in urban areas during the last few twenty-five year periods:

* Notes taken by J. Hoagbin

Date	Percent Urban Population
1850	17
1875	27
1900	40
1925	50
1950	63

The number of people supported by each farmer as a function of time is shown in the following table:

Date	Number of People Supported by Each Farmer
1900	4
1925	7
1950	15

If the man you want to see doesn't live in your town, you can visit him. Rate of travel has increased exponentially. At the turn of the century 40 miles per hour was considered fast. Now we can travel at 300 miles per hour. Plans call for 1,000 mile per hour speeds of travel in the near future.

If you can't travel and you want to talk to the man, you can phone him. In 1900 there were about one million phones. Today there are about 55 million phones. Also in the same period the number of phones per person has increased from one per 100 persons to 30 per 100 persons.

While I will not present the statistics, power generation and business volume have also increased exponentially. It has been said that it is almost impossible to be too optimistic about the way business volume will continue to increase. The danger lies in failing to recognize that it will.

Problem Areas

I have said that this increasing rate of living has given rise to a whole new set of problem areas. In transportation, for example, we now have problems with air traffic control, ship traffic control, rail traffic control, and bus traffic control. Problems have arisen in the areas of communications, war, science, and industry. The business data processing problem is just one more manifestation of the whole problem of the faster rate of living.

What are the characteristics shared by all these problems?

First, all of the problems in these areas show complexity. There are many variables. If one variable is changed, a whole set of other variables also change. Values of variables can be traded off. In an air defense system, for example, increasing the range of the weapon changes the radar requirements. Increasing the speed of the weapon changes the weapon and radar requirements.

Secondly, these problems show multiplexity. When things happen, they happen in many ways and many times. Today it is possible for any one of 55 million phone subscribers to call any one of 55 million phone subscribers.

Thirdly, the inputs are statistically distributed with time. It is possible to know the average rate of arrival of inputs but one cannot say what will be happening at any given moment. For example, the arrivals of planes at an airport, cars at a toll gate, the number of phone calls being made, the number of enemy targets, all vary statistically.

The fourth, and last characteristic is the presence of the human element. Most systems involve human operators or human customers. Systems composed entirely of humans or entirely of equipment are not as difficult to operate as systems composed of men and machines.

Solution Characteristics

The problem areas arising from the increasing rate of living show these common characteristics. The solutions will not have exactly the same characteristics but will take them into account.

For example, one will find feedback in the solutions. Feedback is important in a complex system. If one variable changes, others change also, and one must know of the other changes. A complex system has many feedback loops.

The feedback and complexity force an integrated solution. One finds that pieces and parts won't solve the problem. It was once possible to go to an airframe manufacturer and order an airplane. It was not catastrophic if you found just before delivery that you needed a radio or a gunsight in the plane. Today the problem of designing an airplane is an electrical engineering problem. After the electronics have been designed, an airframe is designed to go around it. Airframe manufacturers are still associated with planes and missiles because they realize the importance of the system approach and they have on their staffs the system-oriented electronics people required for the design of modern guided missiles, fighters, and bombers. Today's problems require that the integrated whole of the problem be attacked. The probability that two pieces will match without this approach is almost zero. In World War II we encountered this phenomenon many times. Two boxes would be built and later it was found that an adapter had to be designed and built to make the boxes work together. The adapter was frequently larger than the two boxes.

What does multiplexity lead to in the solutions? Frequently the answer is automation if the job to be done can be handled on a routine basis. However, if one is to replace a human by a machine, it is necessary to know how the human performs the function. We do not yet know how humans do some of the things they do.

Statistically distributed inputs lead to the following actions:

1) Speed up the operation by making humans work faster or by automation.

2) Add more channels of the old type. That is, add more operators, clerks, phone lines, or other servors. This choice sometimes adds to the complexity and multiplexity.

3) Allow waiting lines to form. This choice has tremendous effects on the other parts of the business.

If one chooses to speed up operations, automation is probably necessary because humans can seldom be speeded. Adding more channels requires the integrated approach so that interactions will not lead to difficulties. Allowing waiting lines increases interactions of parts requiring more integration in design.

The Human versus Computer

Usually, the choice between the human and the machine will be made in favor of automation when speed, cost, and greater reliability are of great importance to the solution of the problem.

We might discuss the human in computer terminology and compare him to existing computers.

1) Speed of operation: Humans can perform certain data processing functions in about .1 seconds. However, this is an average. Actual times required are distributed statistically.

   Computers can perform similar operations in a few microseconds and at regular, predictable rates.

2) Storage capacity: If we assume that a man can absorb 100 bits per second for a seventy-year lifetime and remember it all, the man can store about 10^{11} bits.

   Modern computers can store (for reasonably rapid access) 10^7 to 10^8 bits.

3) Access time: We don't know how a human is able to do it but he can sort through a tremendous amount of information and recall events and facts in varying amounts of time. A human can recall events that happened many years ago without difficulty. However, sometimes he cannot recall what he wants although he can recall what he doesn't want.

A computer must laboriously search through all of its stored information, but it can recall the right information in a time that varies with computers from a few microseconds to a few seconds.

4) Flexibility: The human is extremely flexible. The human is easy to program and easy to reprogram. The computer must be told to do everything and how to do it. It is difficult to anticipate all of the things the computer will be called upon to do in solving a problem so considerable effort is required for programming. Changes in a computer program are not easy to make and one must think carefully before deciding to change.

5) Reliability: A man is a very reliable device although he is made up of unreliable components. A human is capable of detecting and correcting gross errors. For example, if a human adds two figures, and the result turns out to be smaller than either of the two figures, he will usually catch the error. A computer won't catch such an error unless you put in some error-checking feature at the proper point in the computer program. Humans are likely to make little mistakes and few gross errors.

Computers are more likely to perform error-free and then suddenly fail and make gross errors that are not detected by the computer. We have had a small transistor computer operating without error for 18,000 hours. Of course, this computer performs a simple operation but it does so error-free and very rapidly.

6) Packing factor: The human brain is an excellent computer packed into a space of less than one cubic foot. If you were to build a computer to perform the functions of an ant, several roomfulls of equipment would be required. And even then the computer wouldn't be able to produce little ants!

7) Cost: The operating cost of a human being is large. In terms of power, space, and working conditions the computer is much cheaper to operate.

I don't know what figure to place on the production cost of the human, but I feel the production cost of a computer is higher.

Thus the machine is probably better than the man from the standpoint of speed, operating cost, and reliability.

Dr. Alexander of the National Bureau of Standards tells a story that illustrates the difference between working with people and machines! It is wartime and you are the head of a department doing data processing. All your people have been drafted but you must carry on the work.

Your boss calls you into his office and tells you that in order to alleviate the serious manpower shortage the government is bringing in boatloads of people from Lower Slobovia. These Lower Slobovians, your boss tells you, are hard workers and have no sex life or social life so they will be available nights and weekends as well as all day. Also they are mild-mannered and will cause no labor trouble. To this extent they are perfect workers for your department.

However, these people are not intelligent. For example, their vocabulary consists of only fifty words and it will be necessary for you to work out all of your procedures so that they can be explained in terms of these fifty words. It is all right you are told, to let the Lower Slobovians ask questions, but it is anticipated that following a question session it will take many weeks to clear up the difficulty and get the people back on the job.

And then, Dr. Alexander usually adds, you learn that the Lower Slobovians have a communicable disease and that you will have to communicate by written messages only.

Identification of Business Data Processing Problem as Complex System

The design of business systems requires the approach we have been discussing. Changing one variable in business changes others. A new financial policy affects sales, manufacturing, and engineering. If business were not so complex we would not need managers who have an ability, not yet well understood, to integrate all of the factors affecting the business. Business problems involve multiplexity. Anything can happen. Business is plagued with statistically varying inputs.

Much of the effort of a business is in trying to smooth out these statistically fluctuating variations. I know of a business that bought a computer to do data processing. In an effort to find jobs for the computer, some of the staff were asked what types of problem required solutions.

Two important applications were found. The department in charge of disposing of scrap estimated the company could get two to three times as much for scrap if they knew in advance what and how much scrap there would be. It was also found that vendors would supply material 25% to 40% cheaper if they could be advised of demands four months in advance. This illustrates the high cost of smoothing.

Thus business problems have complexity, multiplexity, and are concerned with statistically varying inputs. Business problems are also concerned with the relationship of the human and the machine.

The System Design Process

So much for the nature of the system problems. Let us now turn our attention to the system design process. During the process there are two areas where work will be going on simultaneously:

1) Exterior System Design: First, there is a clear statement of the problem.

Next there is the building of a mathematical model that shows the relationships of the chief variables.

Then comes the design of experiments so that information can be collected for the model and so the model can be tested against reality.

Then there is the conduct of the experiments so that information can be fed into the model which may have to be revised many times. It is important to note here that the design of experiments should precede the running of them. While this seems obvious, many experiments are performed before their purpose is clear.

The exterior system design is concerned with factors outside the system and is aimed at making the system compatible with its environment.

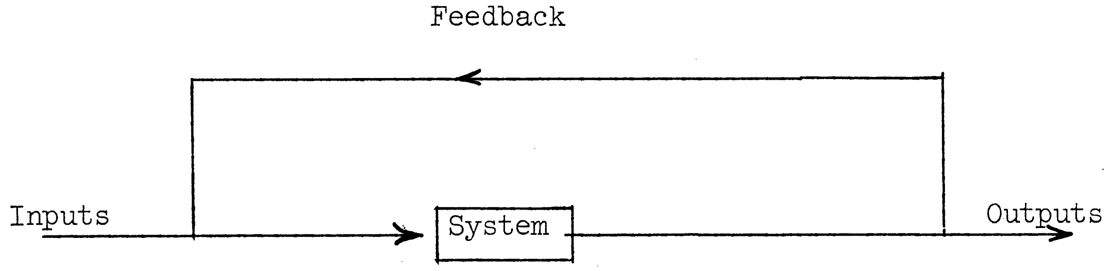
2) Interior System Design: This includes consideration of the single thread in which a single input is traced through the proposed system. Attention is paid mostly to the functions that must be performed and the sequence of functions.

Next comes the high traffic study. Here attention is paid to how often things happen, how much time is required, and how many places things must be done.

Also attention is paid to the competitive aspects of the system. A military system, for example, has competitors who are trying to destroy the system. Business systems also have competitors. A telephone system must be protected from customers who dial before they hear the dial tone.

Let us consider in more detail the system design process. There are usually five phases in the process although they are not always clearly distinguishable.

Phase I Initiation: The figure just below is a representation of an operating system.



This might be a billing system where a certain format in the bill is desired. Hence this problem might begin at the output and require working backward through the system to design a new system to provide the proper format.

Or a problem might arise concerning order handling procedures and one might start by working through the system from the input end.

Actually the problem might arise anywhere. Somebody starts the ball rolling. It might be the manager, one of the engineers, or one of the customers.

During this phase one to three people will usually be involved for about a week to a month. One of the members of the team should know the business including its products, processes, and politics. One of the members should be system minded.

The group will do study and preliminary design. Much of the work will be concerned with the exterior system design. The group will attempt to formulate a clear statement of the problem and they may have a tentative solution at the start of the work. A preconceived notion of the proper solution is not bad if the group is willing to give it up as more information develops.

The product of the study may be a single page report discussing such things as what kind of machine, who is affected, how much, and when. The report may list additional questions that must be answered and may include the tentative solutions.

Phase II Organizational Phase: During this phase the group begins to build to a strength of from five to twelve people. Less than five is not desirable because not enough ideas will be generated.

Greater than twelve people in the group leads to difficulty because communication in the group breaks down and factions develop. More time is spent in discussing which faction is right than is spent in solving the problem. Actually there is no unique solution to one of these problems. A group of intelligent people will usually come up with a good solution. At some point, one solution must be chosen and others discarded.

The group will work for a few months and the output will be another report containing the preferred solution.

During this phase attention is paid to four aspects of the problem:

First there is the system environment or those factors outside the system which will affect the design. Here one must adopt a point of view since the problem may appear different to a department head than to the general manager, for example. The point of view will determine, for example, the choice of machine and location of the machine. It will affect such decisions as whether to let one machine do all data processing for the business, or to let special machines do the special processing for the separate departments.

The solution of a military problem will appear different to a high level statesman and a general. A statesman might recommend economic retaliation as well as military action. An Air Force general cannot be expected to recommend the use of troops for the solution of a problem. A missile manufacturer will not be asked "What is the best way to solve this defense problem?" He will be asked, "What is the best missile?"

One of the reasons the auto traffic problem is so difficult is that there are so many points of view. There are auto drivers, pedestrians, police, firemen, and taxpayers, for example, who are concerned with the nature of the solution. In solving business problems one is more likely to find it possible to adopt a single point of view.

Once having selected a point of view, one is concerned with adopting a measure of effectiveness. The new system design may be judged by speed, capacity, or possibly flexibility. This will depend on the point of view adopted previously.

One must next consider the areas of permissible solutions. It is necessary to have a wide knowledge to know all of the permissible areas and the forbidden areas.

During this second organizational phase an attempt will be made to formulate a mathematical model so that the relationship of the variables can be understood. This model will help the team choose between alternatives. Since many of the numbers for the model will not be known, it will be necessary to design and conduct experiments.

Such experiments can be run without having the whole system at hand. It is better to run simple experiments and to determine, for example, capabilities of operators or equipment (using possibly borrowed components) than to find later that a costly system is unworkable because your assumptions were wrong. Let me state again that it is important to know what it is you are trying to find out by the experiments and to carefully design the experiments before they are run.

Much of what we have discussed is concerned with the exterior design or the factors around the problem that help to determine what the problem is.

Also during this phase attention will be directed to the single thread. Detailed diagrams will be drawn. There will be detailed diagrams of detailed diagrams in an effort to determine everything that can happen. The process is similar to plant design.

During this organizational phase it will be necessary to develop a philosophy of design. An example may make clear what is meant by this: Around 1920 the Bell Sytem conducted a study to determine how many telephone switchboard operators would be needed in the thirties if business continued to increase. It was determined that every eligible young woman in the United States would someday be needed for manual telephone exchanges. So the Bell System set to work to invent an automatic telephone exchange.

It was necessary to develop a design philosophy. The new exchanges could automatize what the human operator does or it could work entirely differently. An operator picks cords, places them in their proper jacks and turns to another switching problem.

The first automatic switchboards employed switches to pick particular connections. The switching equipment was tied up during the telephone conversation. This represented one design philosophy. Present automatic exchanges use switches to set up circuits then free the switching equipment to do other switching jobs. The resulting saving in switching equipment because of this different philosophy is enormous. One must have in mind a design philosophy when designing a chemical plant, a data processing system, or when buying a computer.

Phase III Preliminary Design Phase: This phase is concerned with gathering information about what is available, considering the needs for such things as duplication of information, and compatibility of the parts of the system. Salesmen can supply much of the information. The work will still involve the same five to twelve people.

Judgment must be used in the tentative selection of equipment. For example, one should not specify a two million dollar data processing installation for a two million dollar business. Also before great speed is called for, one must be sure it is absolutely necessary.

The system design during this phase should have more to do with the requirements of the business than with attempting to justify the need for particular pieces of equipment.

During this phase more blocks in the system will get more attention. Input equipment such as electric typewriters and teletype machines will be considered. Attention will be paid to logical control equipment and material handling equipment. Communications equipment such as telephone, paper and pencil, teletype, and automatic switching and transmission equipment will be considered. Also the data processing equipment will be considered.

You will find it hard to make the proper choices without critical experiments. Borrow equipment and run test problems to determine how well the equipment suits your needs for storage and speed. Do not specify the equipment and then try to accommodate your needs. Attempt to find the storage and speed requirements of various computers. You will find that if storage capacity is plotted against the logarithm of speed for the computers being considered, a roughly straight line results. Armed with such a chart compiled from information from salesmen and colleagues, and armed with the requirements found from running test problems, you will be able to select the machine you want and also quickly dispose of many salesmen.

The output of this preliminary design phase is another report: It should

1) Describe the data processing system to be used. This should be a general description.

2) Describe each subsystem and tell what goes in, what goes out, and the functions performed by the subsystem.

3) Suggest implementation. This should be offered as a possible solution only. The functional description in (1) and (2) may be satisfied by other implementations.

4) Give reasons for your choices of equipment. Don't expect your recommendations to be adopted just because they are your recommendations.

The report should, of course, contain estimates of time, people, money and should discuss advantages and disadvantages.

This finishes the preliminary design phase.

Phase IV Principal Design Phase: During this phase the system design is polished. One must start all over again but this time carry the design to more detail.

It should be possible to begin buying some equipment.

A number of tools have grown up to help in the detailed design of systems. Among these are probability theory, large scale computers, and human engineering. Of great usefulness has been information theory for the study of information storage and communications bandwidth requirements. For the study of high traffic density we now have waiting line theory (or queueing theory).

Phase V Installation Phase: During this phase installation is taking place and the training of operators begins.

This is not the time to evaluate the system! The evaluation should have been done during the design phases. However, it may be necessary to test the system to see if it operates as required or specified by the designs. This is also not the time to run tests on the capabilities of human operators using the equipment. Such tests should have been run during the design phases.

TRAINING FOR OPERATIONS RESEARCH*

Joseph McCloskey
Case Institute of Technology

Before beginning my talk, I had better say what I think Operations Research (OR) is. In looking over the list of speakers you have had so far, I feel you have been given every point of view there is except mine.

Some people think OR is new, different, and magical. I don't. From my training as a historian, I feel that OR is a natural development appropriate to our times. Consider the history of science or knowledge. We find back in ancient times only one science: philosophy. Philosophers such as Aristotle and Plato studied and understood everything that was to be known. But down through the ages there have been partitions. In the Middle Ages, natural philosophy split off from philosophy. In the nineteenth century all kinds of divisions developed. Certain common areas in physics and chemistry, for example, were not placed in physics or chemistry but were combined into a new field known as physical chemistry. Increasing specialization has become necessary to the mastery of knowledge--but in particular areas.

We now find that many jobs cannot be done by specialists working alone. Team research is needed, for example, to produce a radar system, or a new military aircraft, and the amount of work requiring team research is increasing. Recombining of the separate sciences must be accomplished without sacrificing depth in each field so that simple generalization is insufficient. This need can be met only by mixed teams of, for example, physicists, mathematicians, psychologists, and economists.

Now let us consider the management function and how it has changed. As late as the 18th century, one man owned the business and made all the decisions. He was the salesman, production manager, and accountant. As the technology became more complex, specialists began to emerge to assist in the management function. First came the civil engineer, then the mechanical, chemical, and electrical engineers to help managers to make decisions. Late in the 19th century the concept

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* Notes taken by J. Hoagbin

of the "general staff" was born. Today, the executive is surrounded by staff and line personnel to help him make decisions and to share his responsibility.

It is interesting that, until recently, little research has been done on the management functions. The executive was caught in the cross fire of increasing requirements for decisions and the increasing complexity of the business about which he was making decisions. No research was done on his problem until about twenty years ago when the economic analysts appeared, followed by business statisticians, management engineers, and many others. More recently, OR people have appeared, dedicated to assisting policy-level management by the use of research conducted by teams composed of people with whatever backgrounds are necessary for the problem at hand.

Hence OR is merely filling a need not recognized in past generations but now recognized. OR is research for management. Uniquely, it helps management at the executive or decision-making level.

One often hears that today's problems arise because we no longer have geniuses like Vanderbilt, Wanamaker, or Rockefeller, but I believe that if these men were confronted with some of the problems present managers have, they would wind up in jail or in a straight jacket. There are smarter people today; it is just that today's problems are more complex, and today's managers need assistance of the type given by OR.

It used to be much more difficult to interest management in OR than it is today. OR results have been widely disseminated not only by the OR Society and its Journal, but also by the journals and meetings of other technical and management societies. (It is interesting to note that the best managed companies usually get interested in OR. Companies that are doing poorly are usually not receptive to OR work because management tends to be panicky.)

Getting Started

Let us consider how one might get started in a typical organization with a chief executive and several echelons of staff and line elements. It is difficult for someone several levels down to convince the big boss that he needs OR. I know of several instances where employees have interested management in OR by working out a company problem on their own time, but there are better and easier ways of going about the task of introducing OR.

Trying to organize a group from scratch would be very difficult. In a chemical plant, for example, one might select a chemical engineer and give him lots of freedom and time to think, and then sit back and wait for something to happen. Chances are nothing would happen.

At Case Institute we prefer to start out with a combined effort. That is, we prefer to start with a team composed of our people and people familiar with the business. A good mixture is about 50-50 with two to three members from the OR group and the same number from the company. It should be the intent of the company that the people selected are to form the nucleus of an OR group in the company.

If I were setting up an OR team for an organization that was largely engineering dominated, then I would choose a physical scientist, or a mathematician, but I would not pick an engineer as the actual or potential head of the group. If the organization were not engineering dominated, then I would have an engineer or scientist as leader. A second team member would be acquainted with the business; thus, if the business were a fabrication plant, I would pick an industrial engineer or a quality control statistician. The third person I would choose would be an accountant. Accountants are very handy to have on OR studies. They understand the accounting system and costs and they know where much of the data can be obtained and what it means. A good accountant on an OR team can sometimes cut data collection time by a factor of two or three. Without detailed knowledge of the problem we might have to tackle, I would pick the following Case Institute personnel to work on the team: a senior scientist (his particular training would be relatively unimportant), a mathematical statistician, and a graduate student. These six people would constitute a good team to start with.

Case Institute has completed almost 40 jobs for industry with similar mixtures. These have been jobs for a wide variety of industry. Such teams help management with particular problems and help to introduce OR into the business organization.

The team should start working on some complex problem touching on many parts of the business, but not necessarily on the most pressing problem. There should be regular meetings with the executive or an executive committee. Personal contact with management is an important part of the process.

When I first heard of this approach I didn't think it would work. In my brief experience in industrial OR, I know now that it can and does work. For example, we have just completed one study for a large transportation company. Two people from the company and three from Case did the necessary research, not on the most pressing problem, but on a difficult one that touched on many aspects of the company's operations. By the time the work was completed, the company members of the team were fully equipped to tackle a closely related problem; we have moved into the background in a consulting capacity. We anticipate another--and much more difficult--problem with the same company. We hope we will be asked to step back in on a full-participation basis. By the time that study is complete, I doubt that many problems will prove too big or too difficult for the internal group thus being developed.

While the Case Institute personnel try to become consultants as quickly as possible in the combined OR team, usually the senior scientist from Case is the leader of the group. This is a desirable arrangement because in this way the representatives of the company have no boss staring down their throats.

Place in the Organization

There is a large and flourishing management consulting industry but no OR group that I know of operates like a management consulting organization. Yet management sometimes thinks that OR work can be "bought" in the manner of other consulting services. Actually, so far as I know, every consulting-type OR group is convinced that OR can be done only by an internal group.

The reason why OR should be done by a group in the company and not by outside consultants is that the latter require considerable time to become familiar with the business--and then take their knowledge away with them. For real payoff in OR, continuous study and increasing understanding of the organization is essential--and these are possible only for an internal group.

Because training costs time and money, frequently there is an effort to get OR off to a flying start. Many companies want people to be busy and look busy. It is easy for a physicist or a chemist in the laboratory to look busy. When an OR effort is started, one must anticipate many bull sessions while people are getting acquainted with each other and the problem. Production will be slow at first. It is important for the company to: (1) exercise patience; (2) give workers a genuine opportunity to concentrate on the new job (it must be the team's whole effort and not just an added assignment); (3) it doesn't matter where the team is attached for rations and quarters. If the janitor has room for the desks and people, assign the OR people to the janitor. The administrative structure doesn't matter. The technical side does, however. Results must go to the "boss" or to an executive committee that can benefit from and implement them. An example will show how strongly we feel about this. Recently we started a study with a company where we followed the procedure I have discussed. We conducted a preliminary feasibility study and isolated a problem that was worth working on and yet would provide valuable training for the company personnel. One official of the company was enthusiastic about the preliminary report and a full-scale study was begun. One month later the team showed up for a meeting with the management committee. The management people were not there and so we stopped work on the study. We feel that we cannot work with a company unless the people who can guide us and make use of the information are interested enough to participate at critical times.

In another case we came close to stopping a study. Here most of the representatives of management attended the regular meetings but one or two key men were usually absent. We persisted and it finally paid off. When we delivered the final report, all key management personnel were there and were enthusiastic in their evaluation of the worth of the work. It is now being implemented.

The OR work must be important to people at the policy level or OR can't do its job. Results of OR work must be reported to the point of convergence of control over the controllable variables. We have been discussing reporting to company presidents. In one study for a large corporation, Case Institute did not report to the president but to a works manager because the works manager was in a position to control the controllable variables. Results must be reported to the "executive" who controls the variables, no matter what his status in the organization may be.

Selecting Personnel

People who do OR must be carefully selected for ability to do the type of problem handled by OR. It is not a business for narrow physical or mathematical scientists. Some physical scientists are like the householder who buys a screw driver and then decides to become a do-it-yourselfer. He goes around the house looking for jobs he can use the screwdriver for while ignoring many more important aspects of being a householder. If the OR job at hand requires an ancient historian, then you should have an ancient historian for the job. Incidentally, my training is in ancient history and Florence Trefethen, who co-edited with me the first volume of Operations Research for Management, is an authority on medieval witchcraft!

People selected for OR work should not be narrow specialists. I have yet to meet a physicist, wedded to a laboratory, for example, who has made out in OR. When I was personnel man at the Johns Hopkins Operations Research Office I once interviewed a low temperature physicist. The guy ate and slept low temperature physics. When I attempted to draw the conversation away to other things, he insisted on returning it to low temperature physics. I honestly think he was born with a low-temperature thermometer in his mouth. I advised him not to get into OR.

By contrast, the training of Ellis Johnson, Director of ORO, includes a B.S. in electrical engineering, an M.S. in mathematics, and a Ph.D. in physics. He has had experience in the Navy as an officer and experience as a civilian scientist for both the Navy and the Air Force. Now, of course, he works on problems for the Army. Russ Ackoff, a colleague, has training and experience in architectural engineering, mathematics, and philosophy of science, as well as experience in the Army. For OR we want people who are not satisfied with the answers one gets from any particular science.

Also people chosen cannot be condescending. Somehow people tend to have loyalty to their own fields and think that all knowledge is contained in their fields. They disdain knowledge from other fields. I was one of the few non-physical scientists at ORO. It took some time before I established the right to be in the building. Avoid selecting people who might make cracks like, "All psychologists are crazy," or who otherwise speak of the baselessness or inadequacy of the knowledge of other fields.

This tolerance of other fields does not seem to be built in, but the person selected must be willing to be trained or capable of being trained in working with--and accepting the capabilities--of other kinds of specialists.

In sum, the properties one would like in an OR worker are:

1. He should want to work on the type of problem.

2. He should have confidence in research and the results derived from research.

3. He should not be a narrow specialist.

4. He should not be condescending.

Of course, one would like to add a fifth characteristic: "He should be a genius." Everyone wants geniuses, but I think that OR may be viewed as an organized activity which tries to make up for the shortages of managerial geniuses in our society.

In choosing personnel one should look for some degree of maturity. After some experience with hiring people with bachelor's degrees, fresh out of school, ORO adopted the policy of insisting on higher degrees or at least a couple of years of experience. This may be related in some way to the advantage of conducting research in a controlled environment before tackling the "messy" problems of OR.

In selecting people one should be careful to maintain a balance of skills. If the operations research group has five mechanical engineers, it is probably a good idea not to add more mechanical engineers. It is difficult to maintain a balance of skills in a small group, hence one must be careful to budget in a way that makes possible bringing in people from outside from time to time so that particular people will be available for particular problems although not on the staff full-time.

Size of OR Group and Number of Problems

With regard to the number of problems to have, there is a rule of thumb. The number of problems should be about 2/3 the size of the group. It is hard to get more than three people to work as a genuine team on one problem. You will find that if six or seven people are assigned to the same problem they tend to divide into two teams of three. Also each of the three people should have a second problem to work on during periods when no work is possible on the first problem. For example, it may be that the team is waiting for data required for the solution of the first problem. Of course, it is always possible to find "busy work" but it is much better if there is a second real problem.

With regard to the size of the OR group, it is interesting that the following seem to be magic numbers: 5, 15, 25, 40, 80, and 125. About 15 people seems to be favored; 125 seems to be the maximum.

Training

There are several categories of training. Some training is for all the people in an OR group while some training is just for some of the people. Sometimes the company cannot afford the cost of giving some of the training to all of the people. There is another division between internal training and external training.

First of all, there must be adequate provision for orientation. There are few geniuses who can come into an organization and grasp the operation at a glance. A new man needs time to look around, to get settled, and to get acquainted. A small investment in orientation pays handsomely later. The orientation period should last for about three weeks or a month. After this time the new man will be anxious to start earning his salary.

Secondly, provision should be made for some kind of internal seminar. Most of the information that can be disseminated to colleagues is highly classified. This goes for industrial as well as military information. A physicist in a university can publish the results of his work. If he publishes a good paper, he may get offers from other universities. If he has done a poor piece of work, no journal will publish his paper. If the work is mediocre but good enough to be published, he will receive criticism from his colleagues who read the published paper. In any case, he gets feedback.

This is not true in OR. OR workers must hide their real work. The internal seminar allows one to compensate for the inability to publish. Colleagues within the organization and selected consultants from the outside can get together and criticize work. Such criticism is very valuable.

Provision should be made for personnel to be able to take advantage of skill courses offered by local universities or by colleagues. Courses in calculus, statistics, and linear programming, for example, can sometimes be organized internally. At ORO we organized such courses, partly because we had many ex-school teachers who were anxious to teach. We organized courses in mathematics, symbolic logic, and fundamentals of economics, for example.

There are many short courses offered by such institutions as MIT, Case, Michigan, and Johns Hopkins. These courses usually last for from one to three weeks. These are refresher courses for some and a means of evaluating OR for others. They are important not only because of their content but also because of the opportunity they offer personnel to talk to others working on similar problems in businesses that are not competing with their own. If all the people present are in the auto industry, there will be little meaningful talk, but a man in the auto industry will talk with somebody in the oil industry.

There are organizations now in existence who provide short courses for industries. George Kimball, for example, while at Columbia organized a course to be given for industries at the company location. Case Institute has given such courses in several instances. There is much saving in time and money because only the teachers travel. Hence, the course can be made available to more employees.

A form of external training available to some personnel are conferences and society meetings. The Operations Research Society of America and the Institute of Management Sciences hold semi-annual and annual meetings, respectively. The meetings provide many contacts with other workers and provide an opportunity for youngsters to be heard and looked over.

Membership in technical societies is also important. One man, for example, did an excellent job in applying queueing theory to a problem of waiting lines. He was a telephone engineer and was familiar with telephone switching problems and the work done by Erlang of the Copenhagen telephone exchange and others. This man saw the analogy between his problem and the telephone switching problem. After six or seven months he developed a theory useful for his particular job. He has said that if he had been able to avail himself of the contacts now provided by the Operations Research Society, he would have known the literature better, and he would have completed his theoretical work in three weeks. Membership in technical societies avoids the necessity of starting every job from scratch. Attendance at society meetings should be large and membership in technical societies should be universal in an operations research group.

DISCUSSION

Selecting First Problem

In selecting the first problem it is wise to pick one that is not too large. That is, too much should not be at stake. Also the problem should not be so urgent that an almost immediate answer is necessary. Certainly the problem should be suited to the personnel on the new OR team. A particular OR team cannot be expected to solve every problem.

The question is frequently asked whether an operations research group should begin on an assigned problem or on one they select. The best answer is that the first--and all subsequent--problems should be selected by mutual consent.

Usually a preliminary feasibility study will yield several possible problems. Two of these, preferably closely related, should be selected. From then on, one study will usually result in a recommendation for a second study.

Cost and Payoff

While operations research is new outside the military, the aircraft industry has been using it long enough to learn that about three to five years are required before there are real payoffs.

There is probably not much payoff for companies that employ less than 200 people. One rule of thumb for estimating the initial fraction of the budget that should be spent on operations research is about 1/2 of 1% of the gross sales of the company. Subsequent budgets can be determined by the worth of the group to the company. Placing one man full-time on Operations Research will cost from $20,000 to $25,000 per year and so the gross sales of the company will probably have to be at least a few million per year.

I don't like jobs where the decision is pressing. We like to allow about one year for the initial effort. This seems like a large amount of time but an example will show what usually happens. In one study the team went into the plant and after the third week there was no set of recommendations but the team was able to point out mill practices that were out of line. The company changed these practices and the saving was enough to pay the cost of the anticipated OR effort on this contract several times over.

When ORO began working for the Army on problems of air defense, it was understood that there would be no answers for at least a year. After six weeks, however, OR prepared a paper which affected an important decision concerning air defense for the Army.

Since about a year is required to get started and since about three men are required, it may cost about $75,000 for outside personnel on an initial study. Operations Research costs money but if you want to solve big problems, you have to spend big money.

After an OR effort has been started, about three to five years will be required before it really pays off in the sense of tackling very difficult problems and producing answers in a relatively short time.

Only after about three years is it possible for the boss to call the OR group and find that someone has the answer to a question or that someone can work out a fairly sophisticated study in about one week, and this is possible only if the knowledge stays in the business.

There is an interesting development that has occurred in some companies: When an opening in an administrative position has come up, it has been filled from the OR group. Personnel in the OR group are most likely to know the most about company operations.

Many companies have found that they receive much favorable publicity from reports of OR studies. They find, for example, that many good people are attracted to the organization. One man recently published a paper naming his company and describing its OR work. As a result, 65 people wrote to the company seeking employment.

Sometimes the only assignment an Operations Research group has is to show the company how to increase profits. Actually, the company usually means that they want to increase profits within certain boundaries. In one Case Institute study the OR group suggested a new method which would definitely increase profits but would also lead to labor instability. The company then modified the problem to include labor stability--and the new solution was then worked out.

There is definitely more social consciousness in large companies today. Large companies are interested in more than just increasing profits. This stems partly from the fact that the managers are no longer the owners. The manager has his position in the community to think about, and while his salary may be large, it is not necessarily increased if profits are increased at the expense of society.

In the study of waiting lines at toll gates, the New York port authorities asked for a recommended location for an emergency garage. An emergency garage is required at the end of each tunnel so that cars that break down and hold up traffic can be towed from the tunnels. The OR study showed conclusively that while a third tunnel was contemplated, no additional emergency garage was necessary. This saved the New York port authorities a very appreciable sum, both in initial and operating costs.

In attempting to evaluate OR's work some credit should be given to OR's ulcer rating. Hypertension, heart disease, and ulcers chew up our top executives. There is one study we were not proud of because it showed management that an expenditure of $25,000 a year would yield a net gain of $10,000. Management was very enthusiastic, however, because it showed them how to find an optimum operating point in one of their processes. The study was worthwhile because the company had always wondered how far they were from the optimum and now they had the means for finding out. Thus it was possible to put one worry aside.

Publication of Results

With regard to the publication of company secrets, the OR group is frequently told that they will not be able to publish the results of the study. It is the Case Institute policy to specify in the contract that the methods used in a study may be published. Any proprietary information used must, of course, be cleared with the sponsor before publication.

Watch Third Anniversary

When you have set up an OR group and have trained people, watch the third anniversary. For some reason there is something magic about three years of experience. In any case, after about three years with your company, you may find your people leaving. This may be due to the fact that they are now ready to tackle larger problems than your company has to offer, or it may be that they feel there is no chance for advancement. Your people will be encouraged to leave by many companies who feel that an excellent way to get started in OR is to pirate help from an existing OR organization.

THE DEVELOPMENT OF A MODEL FOR A COMPANY OPERATION*

Roger R. Crane
Touche, Niven, Bailey and Smart

The purpose of my talk is to report a case history. I will give a chronological description of successes and failures in a study of a large paper company. No effort will be made to generalize from this single case. Indeed, not enough case histories have been reported to make generalizations possible.

Let us begin by examining five steps in applying operations research to a particular problem:

1. Analysis. First one attempts to answer such questions as: What is the real problem? What is this company composed of? What functions are performed? What are the sequence of functions and the times and costs involved?

2. Synthesis. Here one attempts to build a model of the system. That is, one attempts to put together some representation of the elements of the business. This model can be studied to learn the relationships of the important variables and how they affect what the business is trying to do. The representation may be a block diagram, a set of equations, or a computer program, just so the model behaves like the business in certain important respects. Thus, the model is an approximation of the business. Its chief purpose is to permit evaluation of alternative courses of action, and the accuracy required of the model depends on the problem involved. Usually perfection in the model is not required but results obtained through its use must be more accurate than those obtainable before.

3. Testing. Here one attempts to determine how well the model can be used to study the business. For example, work with the model may indicate that changing certain procedures will greatly reduce delays in filling orders. It is necessary to go back to the business to test this prediction of the model.

4. Improvement of the Model. Usually the model must be revised several times before it can approximate the business. One

* Notes taken by J. Hoagbin

may find that the model can be simplified or that it must be made more elaborate, or simply that certain time delays or errors used in the model are not really representative of the business.

5. Application. Once one has developed a tested model of the business he is ready to experiment with the model without upsetting the business. Since the model can be run in less than real time, one can run more tests on the model than would be possible with the real business. Also it is possible to use the model to investigate values of parameters undesirable or impracticable to realize normally in the real business.

FIG 1 A PAPER COMPANY

CUSTOMER:

Negotiates Order with Sales
Forward Order to Sales

SALES:

Controls Allocation of Product
Negotiates Order with Customer
Receives Order
Edits, Prices, and Assigns to Mill
Forwards Order to Central Office

CENTRAL:

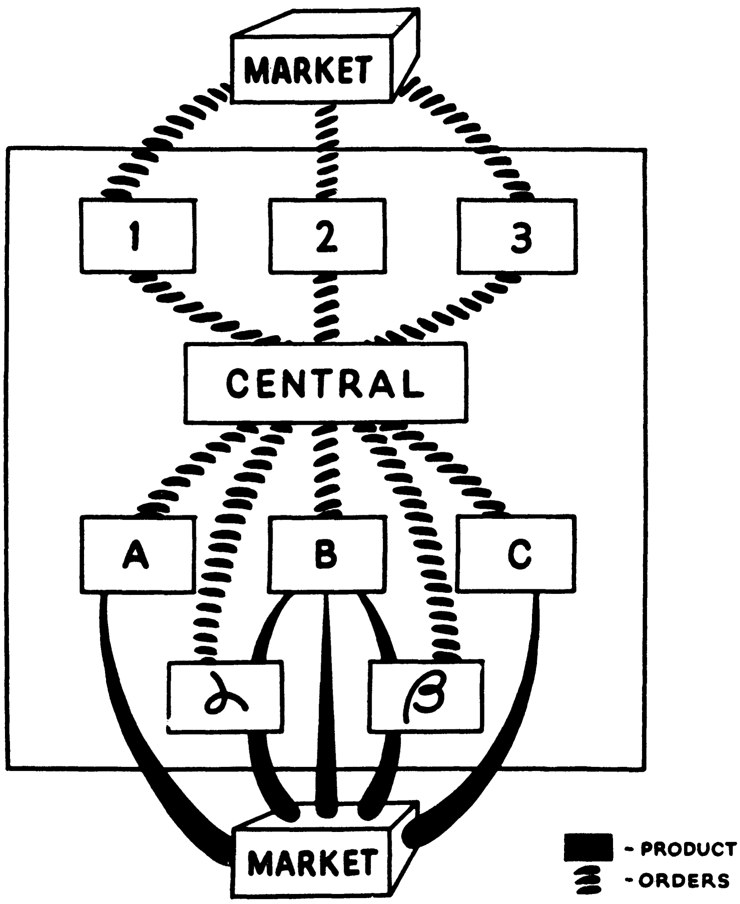
Receives Order
Processes Order
Forward to Mill

MILLS:

Receives Orders
Schedules Orders
Produces Orders
Ships Products

WAREHOUSE:

Receives Orders
Ships Products



Now let us return to the paper company. This company has three sales offices, three paper mills, and three warehouses all widely separated (see Figure 1). The heart of a paper company is the paper machines. Such machines may cost several millions of dollars apiece. Making maximum use of these machines is fundamental to paper-mill economy. This company has over 20 paper machines and makes 2,000 products counting basic weights, sizes, colors, and manner of packaging. The problem of scheduling these and related machines in the mills is a complex one. The problem is further complicated by the fact that at present, if one of the salesmen is about to write a large order, it is necessary for him to determine which of the mills can schedule the order to meet the delivery date required by the customer. That is, there is no central coordinating agency.

This study hinged around this question of the desirability to the company of having such a central agency responsible for final acceptance of orders and for scheduling all paper machines at the three mills.

In a sense this is an organization problem. At present, sales managers report to one vice president and mill managers to a different vice president. If central machine scheduling proves feasible and desirable a new vice president or equivalent might well be necessary to coordinate the two activities. This vice president would fulfill a staff function, and sales and manufacturing would have only one place to which they would need to go to get information. Initial discussion of this plan led to some resistance on the part of sales and mill managers.

The problem of central machine scheduling could have been tackled by a group within the paper company. However, the discussion concerning the desirability of such a move had been going on for some time. It therefore seemed essential to have an outside group evaluate this possibility. Top management decided to call in an impartial agency to determine scientifically whether the plan was desirable for the business.

Late in 1955, we were asked to study this problem. We didn't know whether we could provide a scientific answer but we did know that similar work had been done. We suggested a preliminary study to determine the feasibility of centralized machine scheduling. The question of desirability would be answered later. A team was formed by my firm composed of research scientists and engineers.

In February of 1956 one member of the team was sent to the paper company to become familiar with its operation. He was initially prepared to apply already published application of linear programming to the problem of "trimming" or scheduling paper machines. By machine "loading" we mean determining what jobs will be run on a particular machine during a particular month. Trimming or scheduling determineshow the paper width will be allocated between jobs and which of the jobs can be run simultaneously. This linear programming application provided a specific and useful initial project to carry out while becoming more completely acquainted with the paper mill.

Our man worked about three months on this application of linear programming to the loading of paper machines. For the first month it was hard to get the mill schedules as no one would talk with him. After awhile our man became acquainted with the personnel in the mill, learned about its operation, and began getting the information he needed. The method of scheduling using linear programming was worked out and proved a valuable educational aid to the company although it was not used directly for scheduling.

At the time the study began, experienced men were solving the loading problem using judgment and trial and error. They were utilizing about 90% of the paper width. Our man was able to load a machine to get over 95% utilization of the width. In competing with our man the experienced loaders found they could raise their utilization to over 93%. The paper company was pleased even though they decided not to use the linear programming method.

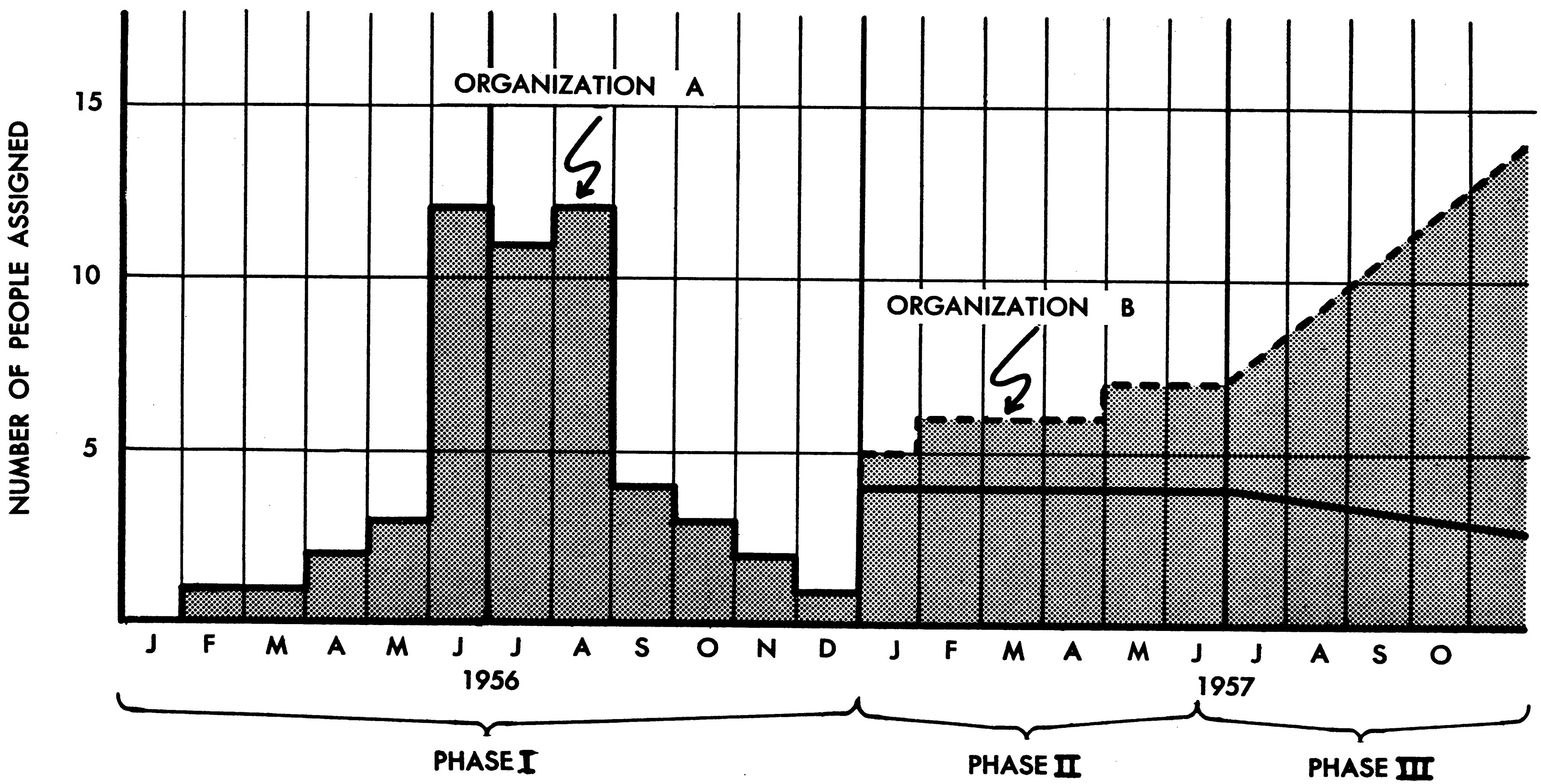
Here is an example of the educational value of operations research. The results obtained with linear programming caused the experienced operators to review their own procedures and improve them.

In May we were urged to accelerate the work so as to have recommendations on central machine scheduling for presentation at an October meeting to be attended by top management and both sales and mill managers. We indicated we could not finish by October, but could complete a preliminary analysis of the business if considerable effort could be put on data collection. We were authorized to spend any reasonable amount of effort in making this analysis. Despite the almost unlimited availability of money, it was evident that only at most a dozen people should be assigned. Not only would too many people just get in each other's way, but also only trained people would be of value, and not many were immediately available.

During June, July, and August (see Figure 2) twelve people were organized into a team composed of CPA's, chemists, industrial engineers, and electrical engineers. While we had hoped the paper company would furnish at least half the personnel for the team, the company was able to furnish only two people.

Most of the team members were not PhD's. A few PhD's contributed materially to the direction of the research effort as indicated in the figure below. Most of the other team members had master's degrees or the equivalent.

FIG 2 MANPOWER ASSIGNED TO PAPER COMPANY PROBLEM IN 1956 AND PLANNED FOR 1957



While the emphasis was on data collection, the modeling was done concurrently because of the influence of the model on the data collected. The manpower pool referred to in the figure was used to supply men to both Analysis and Modeling. The dotted line shows the close working relationship of Research Direction and Modeling. Much time was necessary for collecting such information as time delays for different functions or processes, machine capacities, etc.

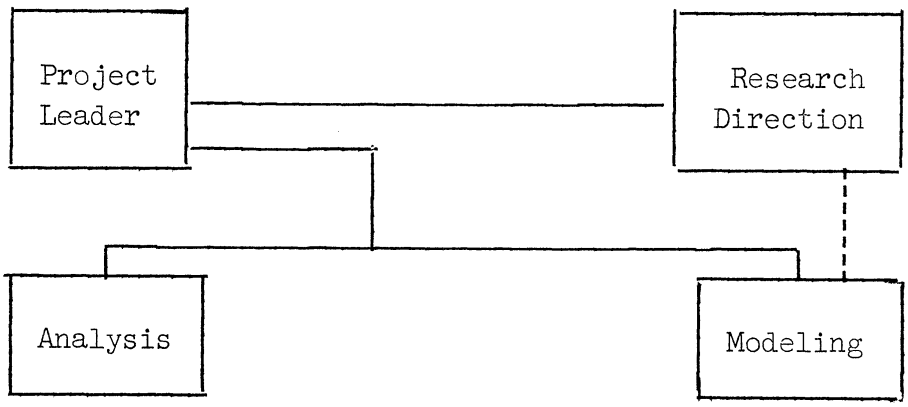


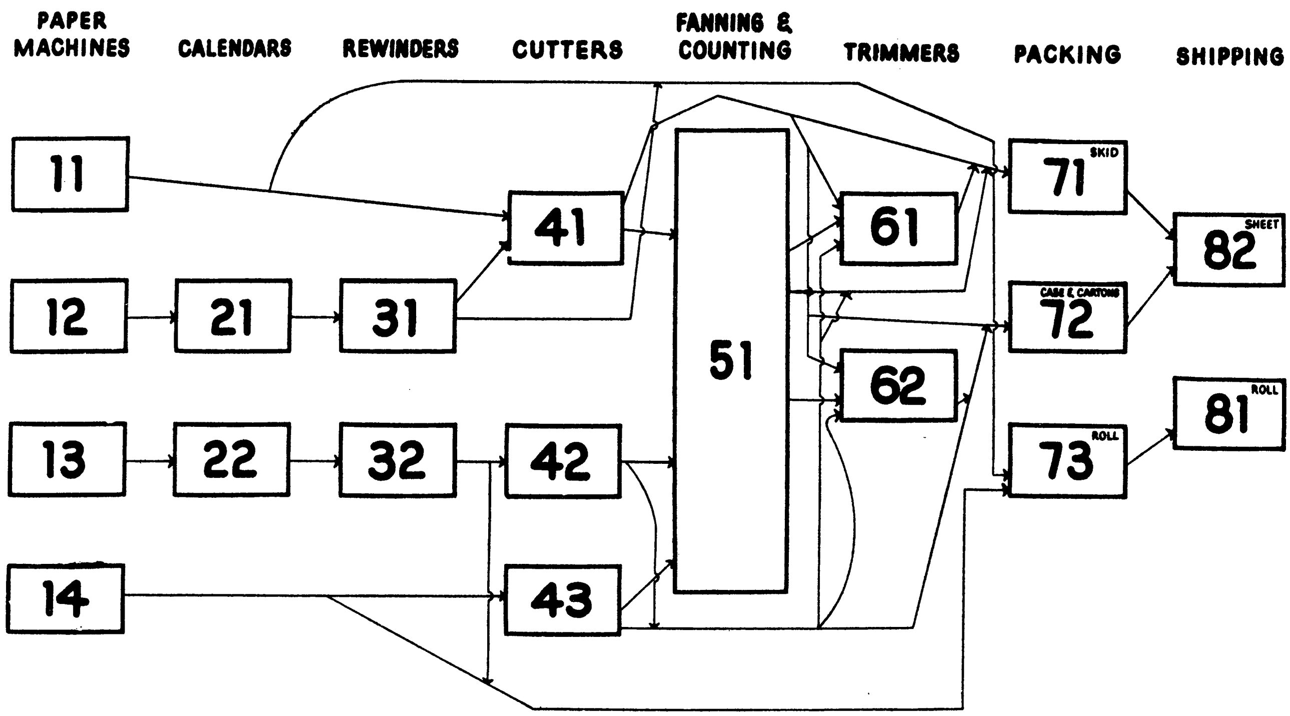
FIGURE 3

ORGANIZATION "A" USED DURING DATA COLLECTION EFFORT IN JUNE, JULY, AND AUGUST.

During this three months of intense study, however, we developed a good understanding of the business and the interrelationships of its component parts. A paper mill performs such functions as paper making, finishing, cutting, inspection, and packing. Not all products take the same route through the mill. In arriving at a block diagram it was necessary to check carefully whether products flow as stated and become familiar with the sequence of events for each product and the fraction that follow particular routes.

Three such descriptive models were developed. The first was too simple. The second was too elaborate and required twenty man-weeks of computation to study a particular setting of the parameters. The third model (see Figure 4), finally adopted, was a compacted version of the second in which we lumped certain machines together. For example, the six calendars in the mill we studied were represented as separate machines in the second model. In the compacted model they were represented as two machines with the capacity of six machines, even though queueing theory indicates that this can lead to some error. Thus, this simplification as was to be expected was only obtained at the expense of some accuracy.

FIG 4 PROCESS FLOW CHART



Since order acceptance determines the inputs to each mill, the model was used to investigate the effect of these inputs on:

1. Total time to process an order

2. Time spent by each order in waiting to be processed at each function

3. Dollars of wasted capacity at each functional station

4. Smoothness of input to particular stations

The criterion for desirability, to be studied later, will, no doubt, involve minimizing costs or maximizing profits for the whole business which will depend on such things as distribution among the functions and of cost of unused capacity. Feasibility, on the other hand, can be demonstrated by actually scheduling paper machines on the basis of the model derived. "Centralized" scheduling was demonstrated to be feasible in this fashion.

Some other reasons for centralized scheduling will now be described.

At present, when a new month is being scheduled, there is no conflict for the first 80% of the orders. However, as the last orders come in, changes are necessary. Over thirty percent of the orders scheduled are later changed for various reasons--often at the last moment. There is considerable discussion in the decentralized system over acceptance of orders and changes in schedules, and there is an apparent lack of flexibility.

To design a centralized system requires consideration of how to accept orders in the future. Salesmen must be permitted to make some commitments to customers. Thus, part of the problem is to determine rules by which the salesmen are to operate in accepting orders. Various rules will affect mill efficiency differently. The question now arises, what is mill efficiency? Not all paper machines can make all products. It would be undesirable to accept orders in such a way that a particular paper machine was not utilized at all. Also, it might be uneconomical to accept orders such that subsequent machines were not utilized as much as the others. Also, we know from queueing theory that it is not generally desirable to utilize each functional station fully since large waiting lines might develop.

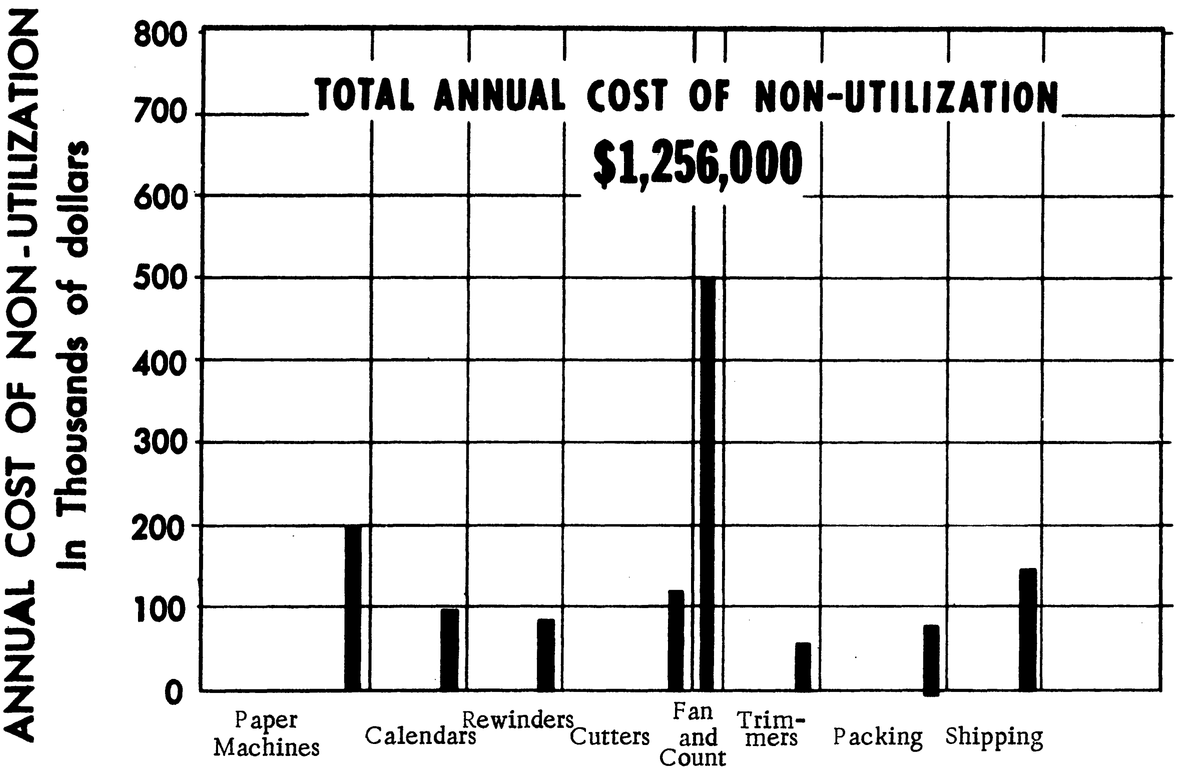
As mentioned above, we chose as a partial measure of a "balanced" mill operation and hence efficiency, equal dollars of unused capacity at each functional station. Of course, one could refuse all orders. With this trivial solution, the wasted capacity at each station would be equal at 100%. Thus, the criterion must include some constraint on the total dollar value of unused capacity.

It was found that it is possible to forecast, by the use of the model, the time to make a product and how long particular orders must wait in line at particular stations. Experimentation with the model indicated it is feasible to schedule paper machines from a remote location.

Figure 5 shows the effect on each major process stage of scheduling the mill in the conventional way, based upon experience. Figure 6 shows the results, using a specified set of scheduling rules. The latter, you will note, decreases the unused capacity by over $200,000 annually in this calculation.

We presented our report to the October meeting attended by about 25 members of top management including sales managers and mill managers. The discussion of the centralized system was intense. Sales and mill managers wanted further proof. It was not yet evident whether central machine scheduling would be better for the overall

FIG 5 PROGRAM NO. 1 OPERATING PERFORMANCE



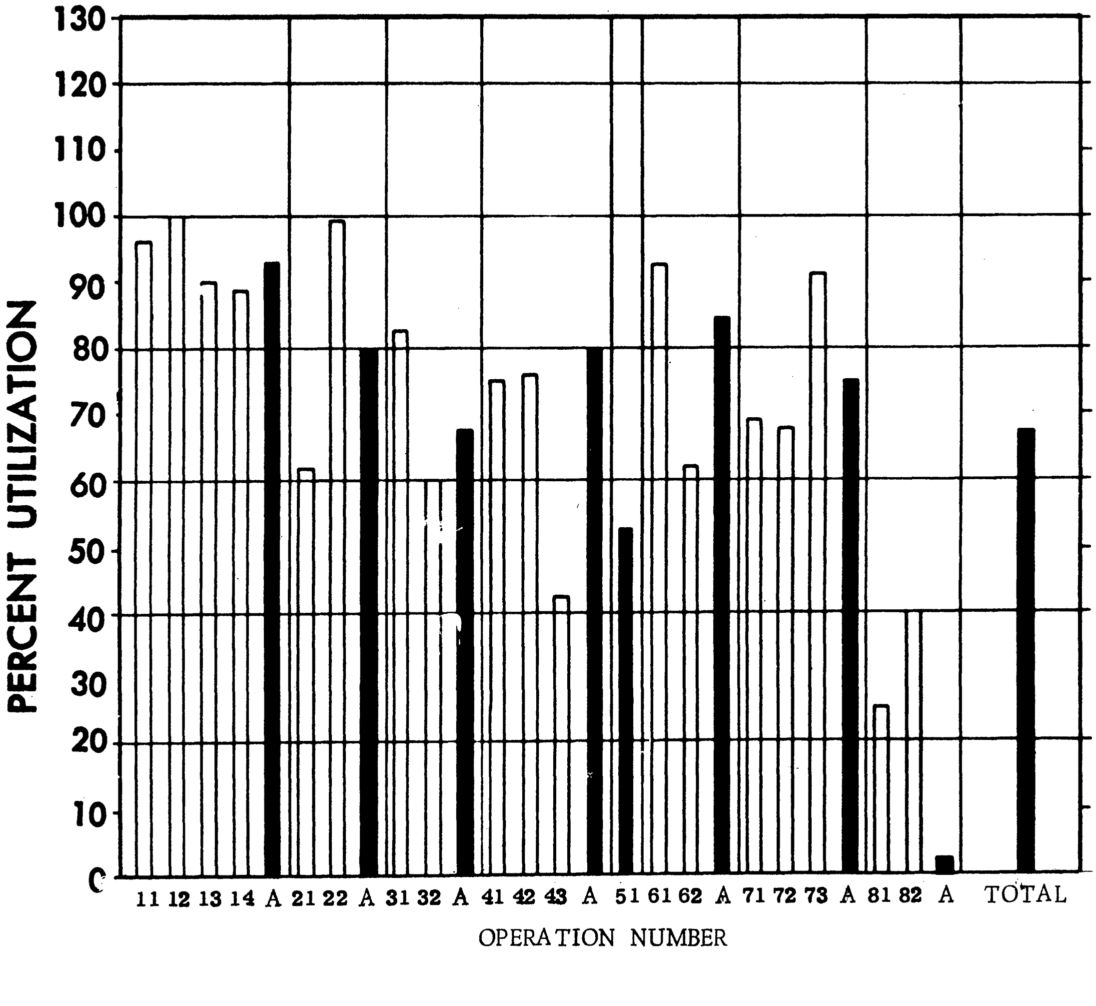
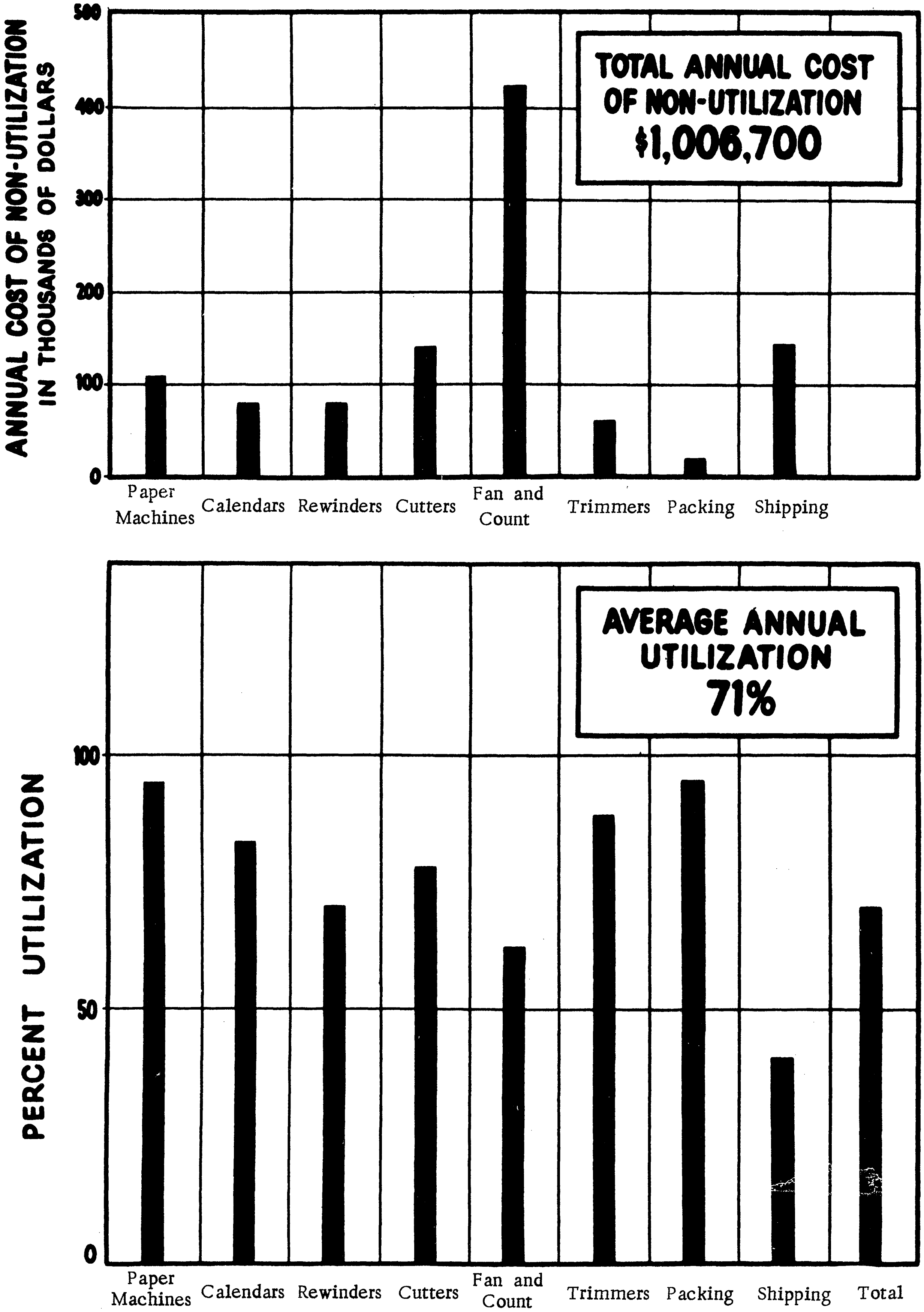


FIG 6 MACHINE UTILIZATION



business, and my firm had not yet tested adequately all of its assumptions in the model.

During the rest of October and during November and December top management did a lot of thinking. They asked our people many questions during this period. Finally, there was a split decision to go ahead with the work. We were asked to demonstrate by mid-1957 that one of the paper company's mills could be scheduled from a remote location. Meanwhile, the paper company would keep a careful record of results. The decision concerning central machine processing for all three mills would come later.

In January of 1957, phase II began with emphasis on the design of a system to handle one mill. This phase will see a more careful checkout of the model, and more detailed study of capacities, machine down-times, and products that can be made on different machines.

The organization being used during this phase is similar to that shown in Figure 3 except that it is smaller (see Figure 2), and the emphasis is on system design as indicated in the figure below.

As with organization A, most of the staff are people with master's degrees or equivalent. Research scientists are used in a staff capacity.

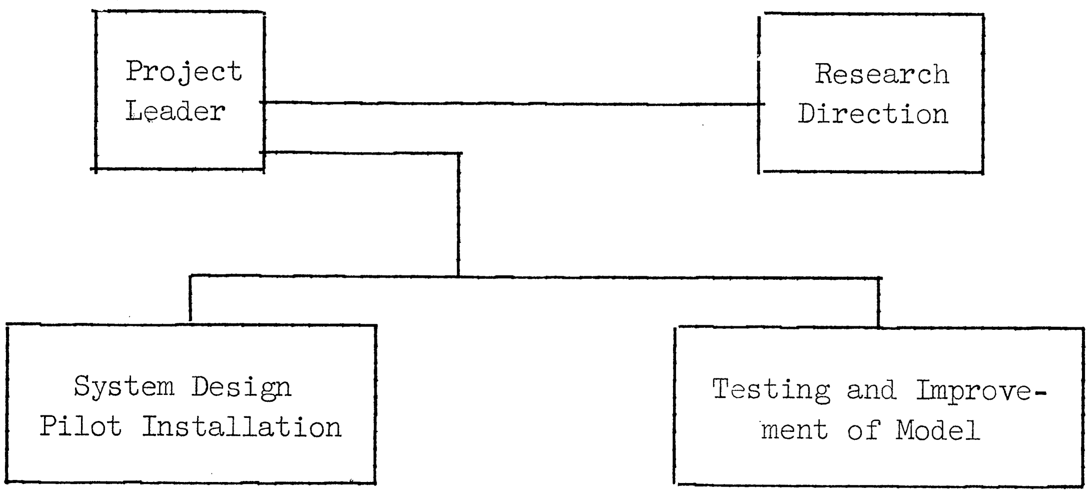


FIGURE 7

ORGANIZATION "B" USED DURING PHASE II.

In mid-1957 phase III will begin. A system design for the whole paper company will come out of this phase. Incidentally, this problem seems to be a natural for machine data processing, but we have not yet decided to use a computer. We will wait until we are sure we need one before specifying a computer in the system design.

As phase III progresses, it is expected that my firm will withdraw from the problem as shown by the solid line in Figure 2. Paper company manpower will increase as shown by the area between the dotted line and the solid line in the same figure.

You may be interested in the allocation of effort on this problem during phase I.

Analysis	20%
Synthesis	40%
Testing	40%

The plan for central paper machine scheduling can win acceptance only if better scheduling results. It is interesting to reflect on the possibility that overall optimization may lead to larger profits for the paper company but to lower profits for a particular mill. This is not likely to happen in the near future since demand now exceeds the capacities of paper companies to produce. It may also be possible to influence the product mix so that a more favorable one can be used in the scheduling. The product mix can be influenced by sales campaigns and by discouraging customers who require uneconomical products.

OPERATIONS RESEARCH AND HUMAN BEHAVIOR*

Rensis Likert
Institute for Social Research
University of Michigan

The Institute for Social Research has been working for ten years to get a better understanding of principles of leadership and organizational structure. I will talk about what we are finding, and I will attempt to show you that you can now take into account some aspects of human behavior when you set up your mathematical models. The purpose of the talk will not be to draw conclusions concerning motivation and productivity, but, rather, to show that these variables can now be measured, that they are important, and that they should be included more than at present in mathematical models.

In general, the design of the studies has been to measure and examine the kinds of leadership and related variables being used by the best units in the organization in contrast to those being used by the poorest. In essence, these studies are providing management with a mirror by measuring and reporting what is working best in industry today.

Briefly stated, some of the findings which are relevant for this discussion follow.

Orientation of Supervision. When foremen are asked what they have found to be the best pattern of supervision to get results, a substantial proportion, usually a majority, will place primary emphasis on getting out production. By this they mean placing primary emphasis on seeing that workers are using the proper methods, are sticking to their work, and are getting a satisfactory volume of work done. Other supervisors, whom we have called employee-centered, report that they get the best results when they place primary emphasis on the human problems of their workers. The employee-centered supervisor endeavors to build a team of people who cooperate and work well together. He tries to place people together who are congenial. He not only trains people to do their present job well but tends to train them for the next higher job. He is interested in helping them with their problems on the job and off the job. He is friendly and supportive, rather than punitive and threatening.

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* Notes taken by J. E. Hoagbin

Higher levels of management, in discussing how they want their foremen to supervise, tend to place more emphasis on the production-centered approach as the best way to get results than do foremen. Workers, on the other hand, tend to place less.

But what orientation yields the best results? A variety of studies in widely different industries show that supervisors who are getting the best production, the best motivation, and the highest levels of worker satisfaction are employee-centered appreciably more often than production-centered. This is shown in Exhibit 1.

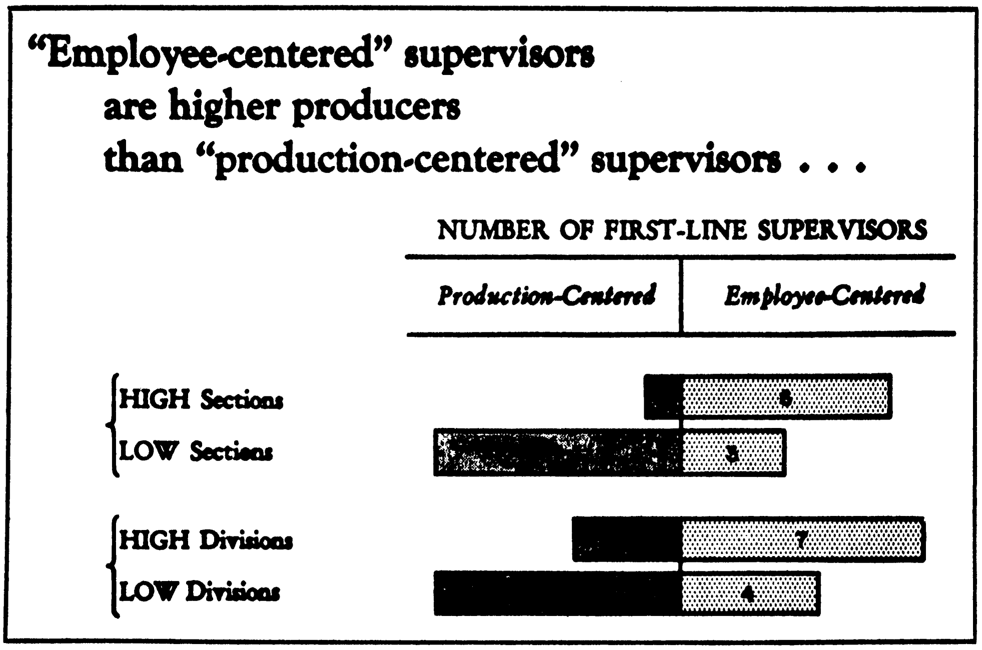

EXHIBIT 1

There is an important point to be added to this finding: Those employee-centered supervisors who get the best results tend to recognize that getting production is also one of their major responsibilities.

Closeness of Supervision. Related to orientation of supervision is closeness of supervision. Close supervision tends to be associated with lower productivity and more general supervision with higher productivity. This relationship, shown in Exhibit 2, holds for workers and supervisors.

Low-production section heads are more closely supervised than are high-production heads . . .

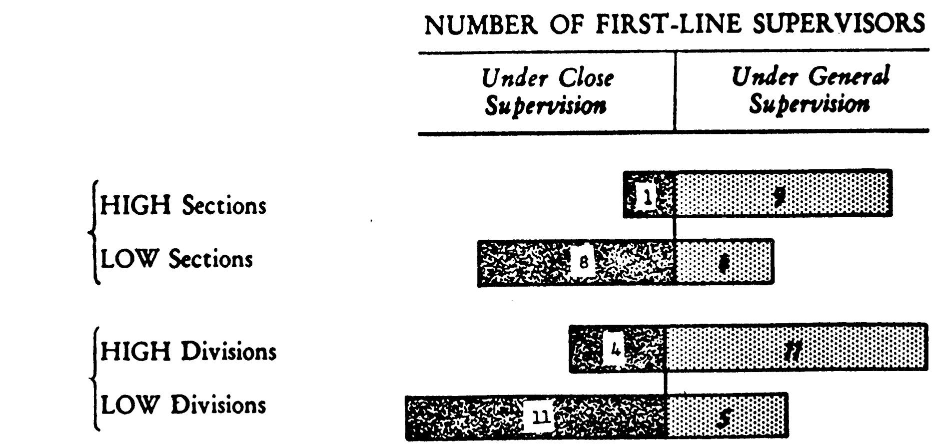

EXHIBIT 2

Low productivity, no doubt, at times leads to closer supervision, but it is clear also that it causes low productivity. In one of the companies involved in this research program it has been found that switching managers of high- and low-production divisions results in the high-production managers' raising the productivity of the low-production divisions faster than the former high-production divisions slip under the low-production managers. Supervisors, as they are shifted from job to job, tend to carry with them and to maintain their habitual attitudes toward the supervisory process and toward their subordinates.

Closeness of supervision is also related to the attitudes of workers toward their supervisors. Workers under foremen who supervise closely have a less favorable attitude toward their boss than do workers who are under foremen who supervise more generally.

Experiment Described

These results which have just been presented on closeness of supervision and on employee-centered supervision were among those found early in the series of studies conducted by the Institute. They led to an experiment which I should like to describe briefly.

As we have seen, the research findings indicate that close supervision results in lower productivity, less favorable attitudes, and less satisfaction on the part of the workers; while more general supervision achieves higher productivity, more favorable attitudes, and greater employee satisfaction. These results suggest that it should be possible to increase productivity in a particular situation by shifting the pattern of the supervision so as to make it more general. To test this we conducted an experiment involving 500 clerical employees.

Very briefly, the experiment was as follows: Four parallel divisions were used, each organized the same as the others, each using the same technology and doing exactly the same kind of work with employees of comparable aptitude. In two divisions, the decision levels were pushed down, and more general supervision of the clerks and their supervisors was introduced. In addition, the managers, assistant managers, supervisors, and assistant supervisors of these two divisions were trained in group methods of leadership.* The experimental changes in these two divisions will be called Program I.

In order to provide an effective experimental control on the changes in supervision which were introduced in Program I, the supervision in the other two divisions was modified so as to increase the closeness of supervision and move the decision levels upward. This will be called Program II. These changes were accomplished by a further extension of the scientific management approach. One of the major changes made was to have the jobs timed by the methods department and standard times computed. This showed that these divisions were overstaffed by about 30 per cent. The general manager then ordered the managers of these two divisions to cut staff by 25 per cent. This was to be done by transfers and by not replacing persons who left; no one, however, was to be dismissed.

Productivity in all four of the divisions depended upon the number of clerks involved. The work was something like a billing operation; there was just so much of it, but it had to be processed as it came along. Consequently, the only way in which productivity could be increased was to change the size of the work group. The four divisions were assigned to the experimental programs on a random basis but in such a manner that a high- and low- productivity division was assigned to each program.

The experiment at the clerical level lasted for one year. Several months were devoted to planning prior to the experimental year, and there was a training period of approximately six months just prior to the experimental year. Productivity was measured continuously and computed weekly throughout the period. Employee and supervisory attitudes and related variables were measured just before and after the experimental year.

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* Methods developed by the National Training Laboratory in Group Development were drawn upon heavily in this training.

Productivity Reflected in Salary Costs. Exhibit 3 shows the changes in salary costs which reflect the changes in productivity that occurred. As will be observed, Program II, where there was an increase in the closeness of supervision, increased productivity by about 25 per cent. This, it will be recalled, was the result of direct orders from the general manager to reduce staff by that amount.

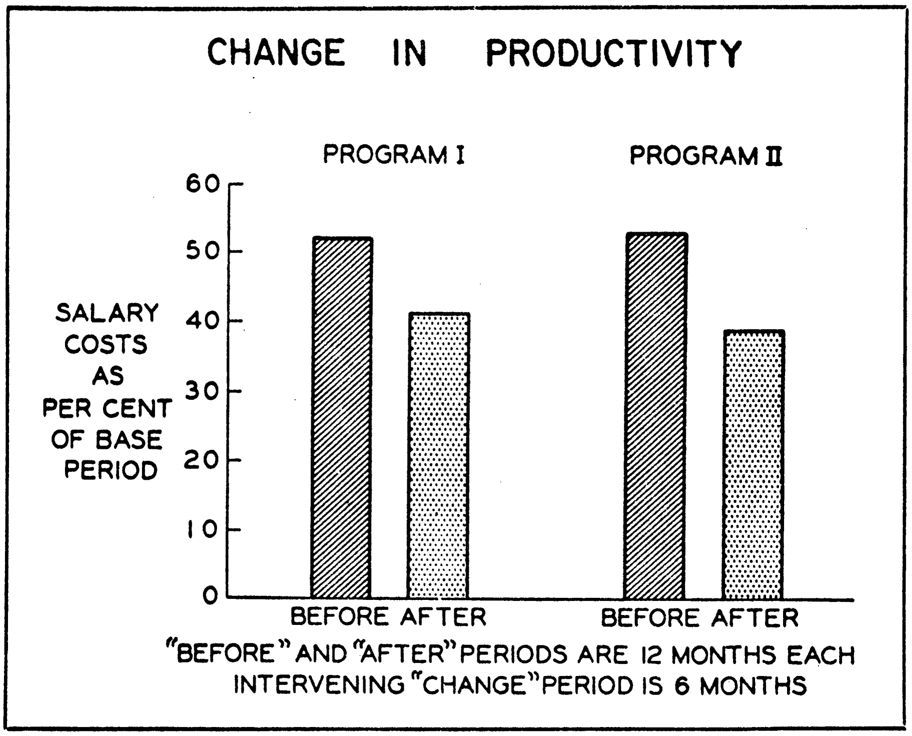


EXHIBIT 3

Exhibit 3 shows, furthermore, that a significant increase in productivity was achieved in Program I, where supervision was modified so as to be less close. The increase in productivity in Program I was not so great as in Program II, but, nevertheless, was a little more than 20 per cent. One division in Program I increased its productivity by about the same amount as each of the two divisions in Program II. The other division in Program I, which historically had been the poorest of all of the divisions, did not do so well.

Productivity and Workers' Responsibility. Although both programs were alike in increasing productivity, they were significantly different in the other changes which occurred. The productivity increases in Program II, where decision levels were moved up, were accompanied by shifts in an adverse direction in attitudes, interest, and involvement in the work and related matters. The opposite was true in Program 1. Exhibit 4, for example, shows that when more general supervision is provided, as in Program I, the employees' feeling of responsibility to see that the work gets done is increased. In Program II, however, this responsibility decreased. In Program I, when the supervisor was away, the employees kept on working. When the supervisor was absent in Program II, the work tended to stop.

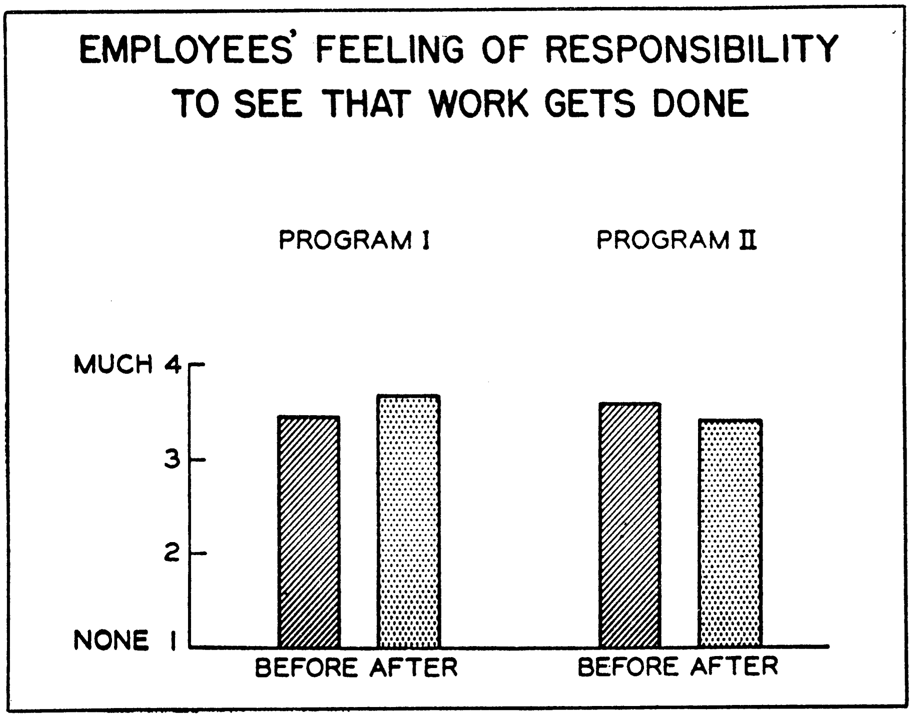


EXHIBIT 4

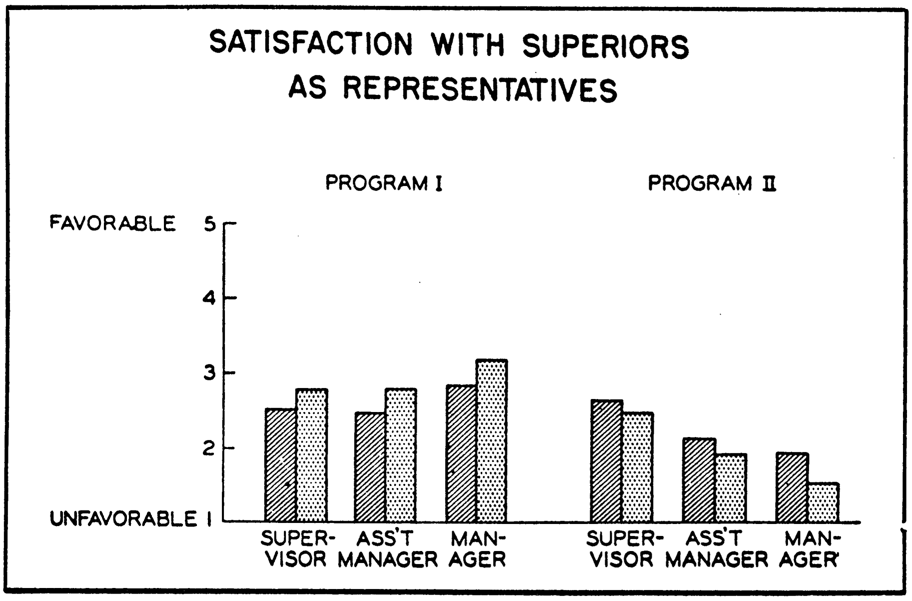


EXHIBIT 5

Effect of Employee Attitudes. Exhibit 5 shows how the programs changed in regard to the workers' attitudes toward their superiors. In Program I all the shifts were favorable; in Program II all the shifts were unfavorable. One significant aspect of these changes in Program II was that the girls felt that their superiors were relying more on rank and authority to get the work done. In general, the shifts were greatest, both favorable in Program I and unfavorable in Program II, for those relationships which other studies have shown to be the most important in influencing behavior in the working situation. A number of other measures of attitudes toward superiors all showed similar shifts: favorable in Program I and unfavorable in Program II.

Fundamental Conclusion

This very brief description of this experiment, I hope, has made clear the pattern of results. Both experimental changes increased productivity substantially. In Program I this increase in productivity was accompanied by shifts in a favorable direction in attitudes, interests, and perceptions. The girls became more interested and involved in their work, they accepted more responsibility for getting the work done, their attitudes toward the company and their supervisors became more favorable, and they accepted direction more willingly. In Program II, however, all these attitudes and related variables shifted in an unfavorable direction. All the hostilities, resentments, and unfavorable reactions which have been observed again and again to accompany extensive use of the scientific management approach manifested themselves.

Probable Long-Term Relationships:

If you take a cross section of any operation, you will find that production-centered supervisors tend to have low-producing groups. (See Exhibit I). Employee-centered supervisors tend to have high-producing groups. You will find that this is true in heavy and light industry and in clerical and professional work. Production-centered supervisors feel that workers should be at a certain place at a certain time doing a specific job. Employee-centered supervisors try to understand people, develop team effort, and are interested in employee problems both on and off the job. They are oriented toward getting employees to know the objectives of the job to be done. They try to get employees to accept responsibility.

We do not yet have enough data to substantiate what I am about to say, but my opinion on what goes on is reflected in Exhibits 6 and 7. They indicate what happens to production, motivation, scrap, and turnover under increased participation of employees in decision making and under increased pressure on employees. It is my opinion that production and motivation slowly increase to some high level, when employees are permitted to participate in decision-making and work under employee-centered supervision. Scrap and turnover fall to some low value at the same time.

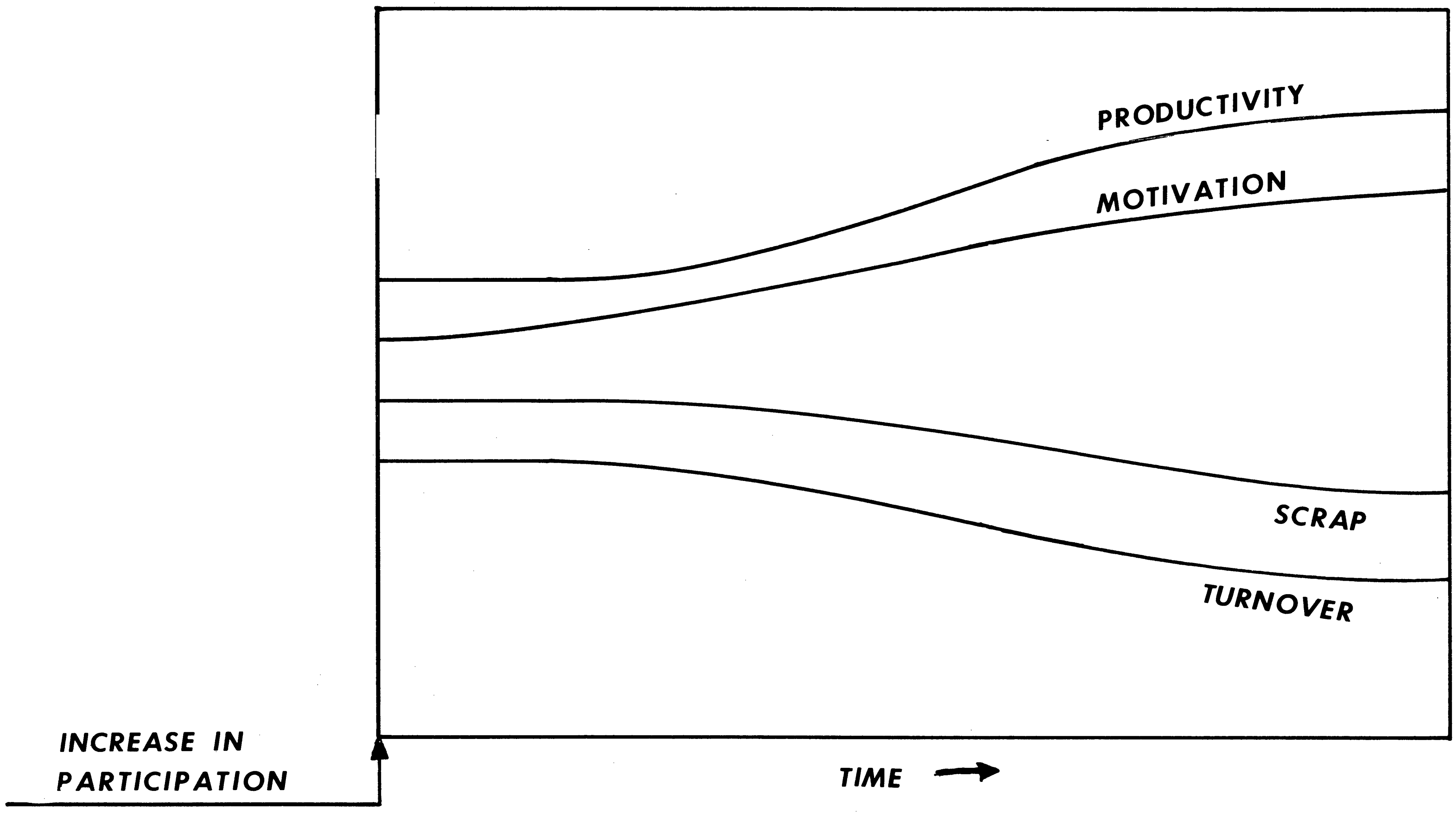

PRODUCTIVITY
MOTIVATION
SCRAP
TURNOVER
INCREASE IN PARTICIPATION
TIME

Exhibit 6

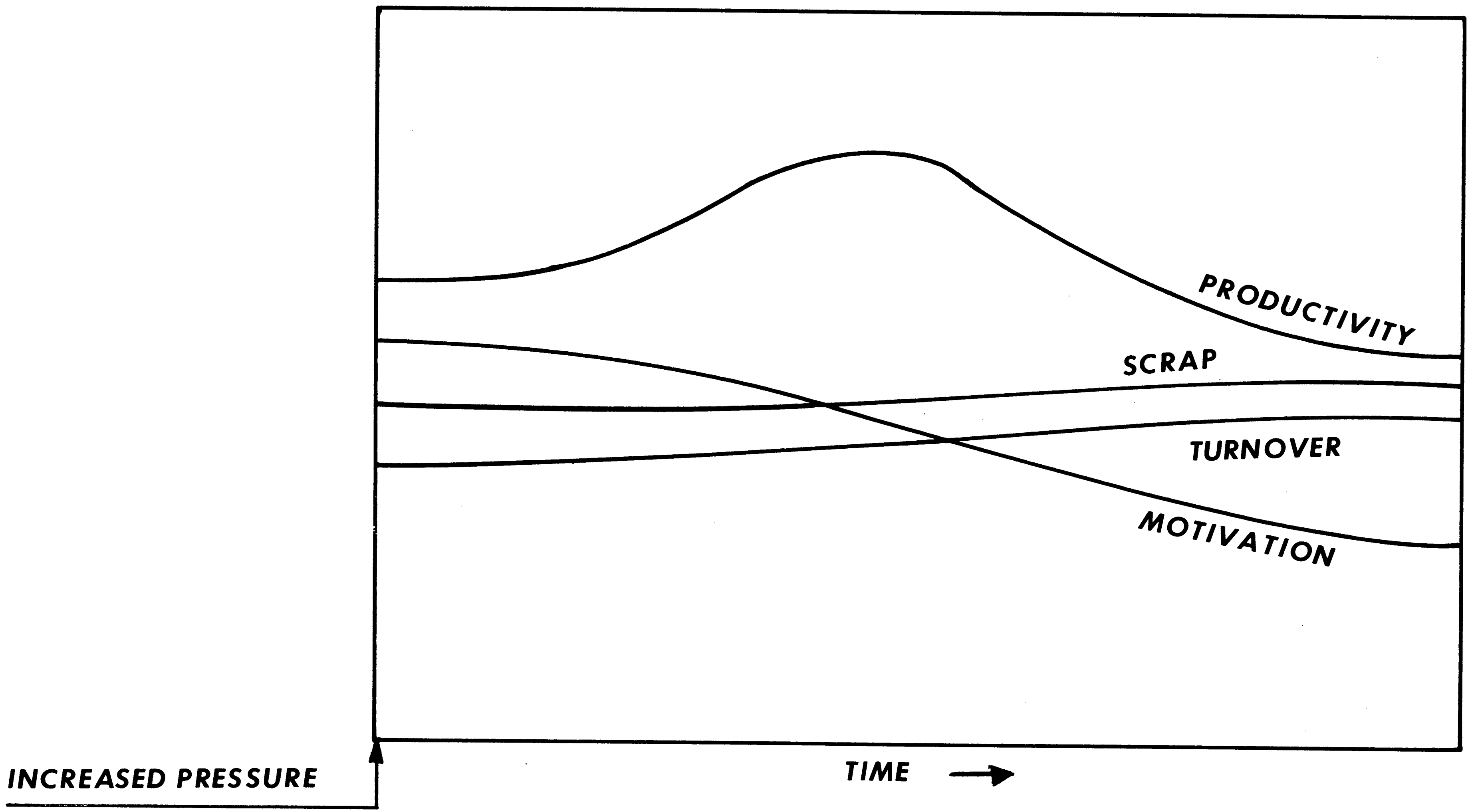

PRODUCTIVITY
SCRAP
TURNOVER
MOTIVATION
INCREASED PRESSURE
TIME

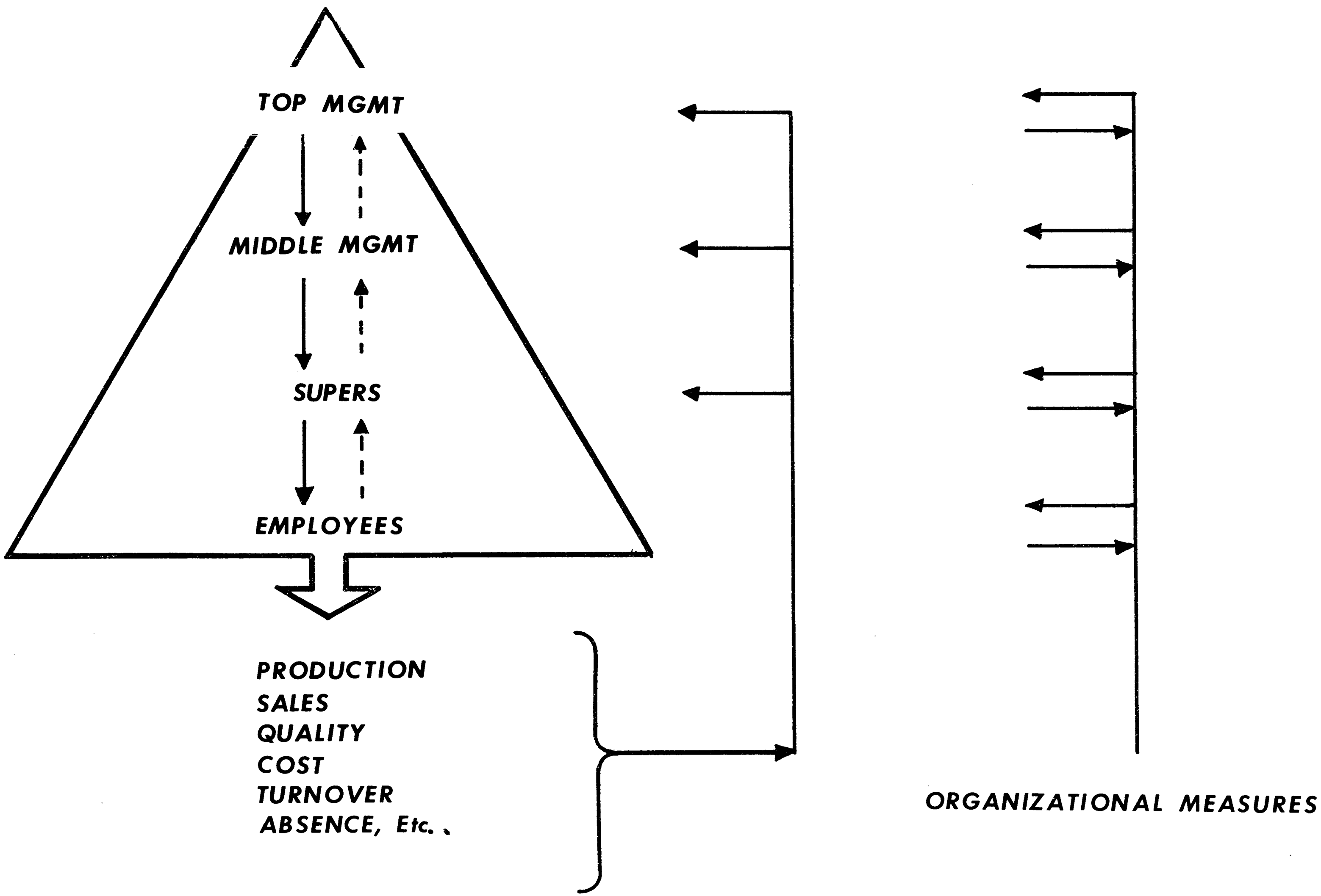
Exhibit 7

When a work group is suddenly subjected to increased pressure, I think that productivity probably increases rapidly to some high value but that motivation begins to fall off. After a while the pressure leads to unhappiness, scrap goes up, turnover increases, people begin to drag their feet, and the result is that productivity ultimately becomes lower than it was before the pressure was applied. This cycle may take two or three years. This type of information is important to Operations Research. More systematic measures of these relationships should be obtained.

Determining Status of the Organization:

Almost every organization does cost accounting on its physical assets, but it is surprising, in view of the large investment in a human organization, that no organization does cost accounting on what might be called "organizational maintenance". Hostility, grievances, and loss of personnel represent deterioration of an asset. Employee-centered supervisors increase this asset.

Communications tend to go, from the top man, down through the organization. Usually, the decisions of the top man are transmitted, with some filtering, to subordinates, (See Exhibit 8) but information going upward is highly filtered. Most people are not frank when talking to the boss. They tend to study him and give him the information they feel he wants. Hence the information going upward is filtered at each level. Top management frequently gets information with errors and distortions. The top man does not really know what is happening in the organization. There is need consequently for "organizational measurements" which will give all levels of management more accurate data than is currently available on the attitudes, misinformation, motivations, experience, behavior, etc., of all persons at all levels in the organization. The arrows at the right indicate how organizational measures should be obtained from all levels in the organization and fed back to all these levels.



TOP MGMT
MIDDLE MGMT
SUPERS
EMPLOYEES
PRODUCTION
SALES
QUALITY
COST
TURNOVER
ABSENCE, Etc.
ORGANIZATIONAL MEASURES

Exhibit 8

These organizational measures should include such variables as shown in Table I. It is important to know what the employees see company goals to be and how they feel about them, for example. It is important also to compare the stated goals of managers, supervisors, and workers. If any have low goals something is wrong.

An indication of the "organizational health" of a company can be learned from how well the boss understands his subordinates, and how well the subordinates understand the boss. It is also important to know how much information, and how much mis-information, each has. One would think there would be little misunderstanding, since in almost every organization the superior prepares regular reports on subordinates. Yet, we find serious misunderstanding at every hierarchical level. Exhibit 9 shows some typical results. These are from lower hierarchical levels in the company. These results are from a large manufacturing company in which time standards have been set for a substantial proportion of the jobs. Actual productivity is expressed as a percentage of each time standard. Expected production is, of course, 100% of the time standard. Each vertical line shows the answers for the foremen whose work groups produce the percentage of standard shown at the bottom of the line. Similarly, these vertical lines show the answers of the workers whose actual production is shown at the bottom of the line. The horizontal lines show the answers to the different questions for the different groups as designated. Thus, the top line shows what the foremen feel to be the production that management expects. Low producing foremen (67% of standard and below) feel management expects about 97%. Foremen whose work groups produce at 82% or above feel that management expects about 100% of standard.

The next line, the line of dashes, shows what the men believe the foremen feel is a reasonable production figure. The low-producing men feel that foremen expect about 95%, while the high producers feel foremen expect about 100%.

The solid line shows what the foremen, themselves, believe is a reasonable production figure. It varies from 82% for foremen whose workers produce 67% and below to 100% for the high-producing foremen. The next line, with a long dash and two dots, shows what the foremen believe the men feel is a reasonable production figure. The bottom line shows what the men, themselves, believe is reasonable production.

Even a cursory examination of these results shows that there is a serious discrepancy between what the foremen think is reasonable production and how the men feel about it. Even more serious, the foremen do not even realize how different these views are. Moreover, the men whose production falls below 93% believe the differences between their view and their foreman's view, as to what is reasonable, to be greater than it actually is. They magnify the conflict.

TABLE I

1. COMPANY GOALS

Concept of information		earnings
Information or misinformation		product
about	re	quality
Acceptance of		reputation
Motivation to help achieve		sales

2. GOALS OF SUB-UNITS

   Of superior

   Of work group

   Of individual

3. ATTITUDES TOWARD, LOYALTY TO, CONFIDENCE, OR TRUST IN

   Superior

   Work group members

   Subordinates

4. ACCURACY OF UNDERSTANDING OF

Superior	Information
Peers	Motivation
Subordinates	Goals, etc.

ACTUAL PRODUCTIVITY AND MEAN PERCEIVED REASONABLE PRODUCTIVITY FIGURE

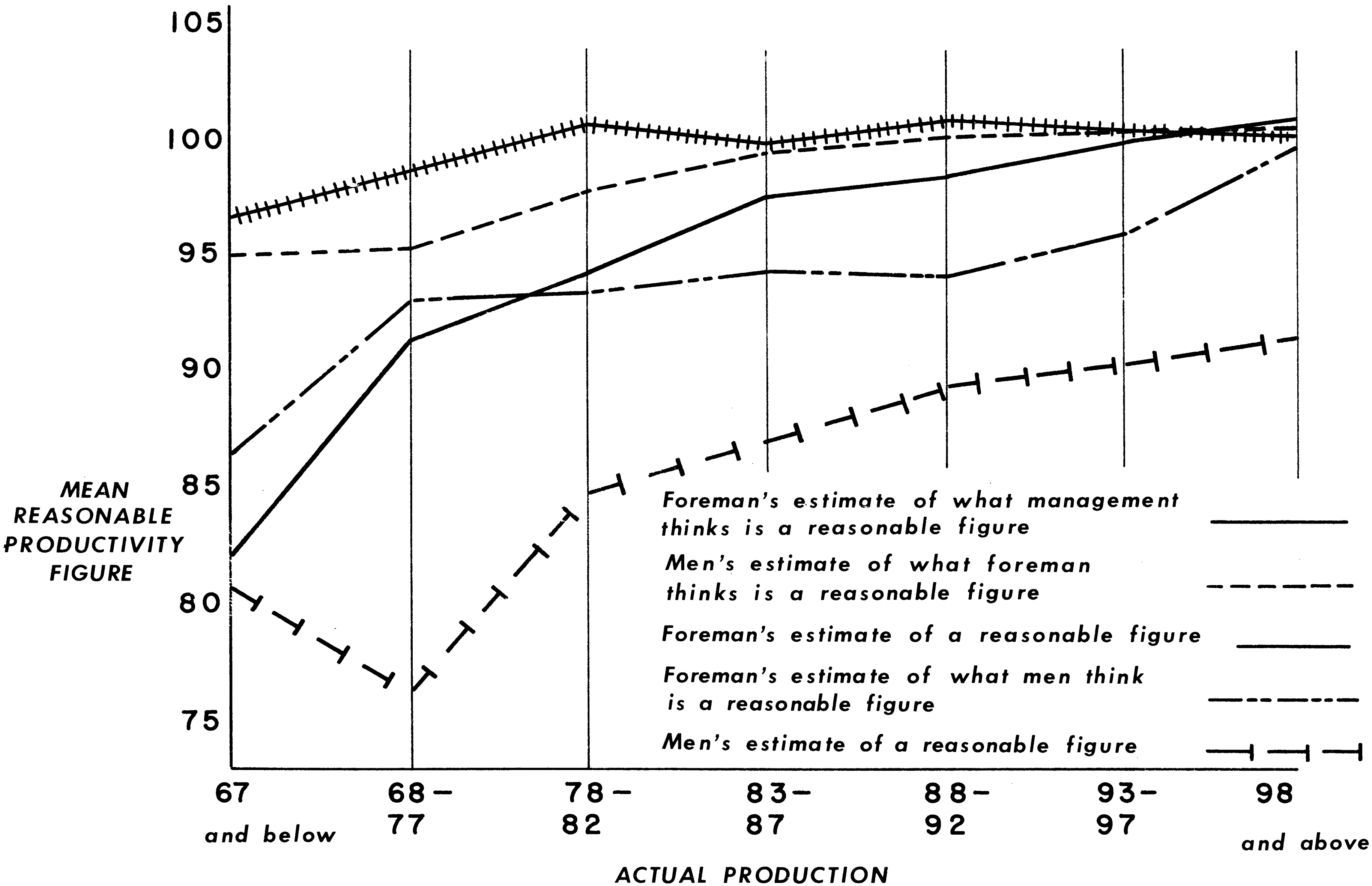


Exhibit 9

Here is a situation involving several thousand men in which there is close personal contact every day. In spite of this close personal association these substantial errors exist in how each group believes the other group feels. No wonder there is difficulty in dealing with problems of production when both groups generally are wrong in their assumptions as to how the other group feels.

In several companies we found that most supervisors felt subordinates were consulted or involved in most of the decisions affecting them. About 70% of the supervisors felt this to be the case but among the subordinates only about 25% of them held this view. Here again there is evidence that for an adequate analysis operations research needs to include more "organizational measurements".

Training

It is important to know whether the superior understands leadership skills, and whether subordinates understand membership roles. Large sums of money are spent by companies on human relations training. Yet, often there is little increase in performance as a result of this training. In fact, there is some evidence that such training at times may have an adverse effect. In two studies by Ohio State University, data were obtained in which supervisors given human relations training required about two years to get over it.

One reason for the poor showing made by some human relations training courses is that most of the people who take them feel that they do not need the training. Each student sits in the course and says to himself, "I don't need this stuff. My boss should be here!"

It is not enough to train for leadership, one must also train for membership. Best performance comes from high group loyalty and good team effort coupled with high performance goals. This requires supervisors who can communicate and exert an influence upward as well as downward. Successful supervisors perform what is known as a "linking pin function". As Exhibit 10 indicates, each supervisor is a member of two teams: the one he supervises, and the team supervised by his boss. He must be able to influence his subordinates, his peers, and his superior. The Institute for Social Research, sometime ago, ran a study in a large public utility employing several hundred people. When we related supervisory behavior, as reported by the supervisors, to employee attitudes on some fifty different items of supervisory behavior we found that several relationships failed to conform to our expectation.* Further

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* Donald C. Pelz, "Power and Leadership in the First Line Supervisor", Ann Arbor, Michigan, 1951.

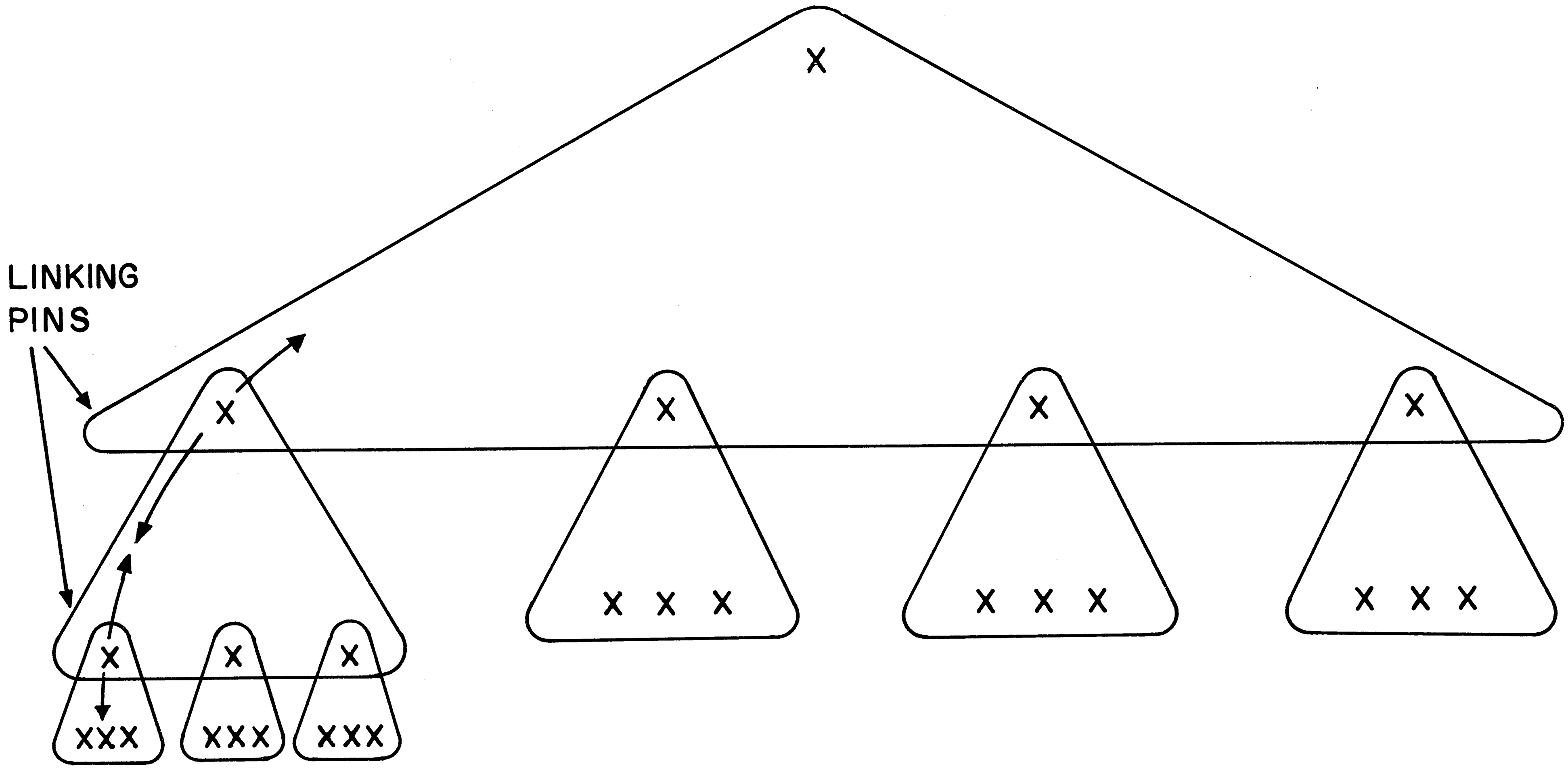

Exhibit 10

analysis suggested that this failure might be due to the influence of other variables. Thus, we found that large work groups tended to have poorer morale than smaller groups, that blue collar workers tended to have poorer morale than white collar workers, etc. When the data were analyzed separately for large and small groups; blue collar and white collar groups; men and women; a very surprising result was obtained. We found that more items of supervisory behavior had a relationship with employee attitude but that this analysis increased both the negative and positive correlations obtained. Thus, for example, we found among white collar men employees who have not finished high school that the more supervisors gave honest and sincere recognition for a job well done, the greater was the adverse effect upon employee attitudes. These negative relationships were surprising and perplexing.

Fortunately, the person conducting this research was a keen analyst and noted some clues in his data which were consistent with a finding in a previous study. He suspected that the power, influence, and prestige of the supervisor in his relationships with higher management might account for the negative relationships discovered. Fortunately, there were data in the interviews with supervisors which permitted the analyst to develop a rough measure of the influence that different supervisors exerted.

When the data were analyzed separately for supervisors with high influence and low influence, the following results were obtained:

	For High Influence Supervisors	For Low Influence Supervisors
Relationship between supervisor's behavior and employee's attitudes:		
No. of Positive relationships	= 19	8
No. of neutral or negative relationships	= 9	20

These results show that when supervisors, whose relationship to their superior is one in which they can exercise more than average influence, use good human relations practices, it has a favorable affect upon employee attitudes. On the other hand, when low influence supervisors use these practices, an adverse affect upon employee attitudes occurs.

When a supervisor who has little influence with his superior tells an employee he has recommended the employee for a promotion, it is not too likely to be acted upon. Nevertheless, the employee upon being told by the supervisor of the recommendation expects the promotion and reacts unfavorably when it fails to materialize. Similarly, when a foreman tells a worker how well he has done a particular job, the effect may boomerang if the worker has a high school education or less and the worker knows that the foreman has insufficient influence to alter a company policy which prevents the worker being promoted above his present job level.

As the above results indicate, an important finding is that the attitude of the employee is affected by his expectations. Consequently, for operations research it is important to measure each individual's (a) experience; (b) expectations and (c) attitudes. Attitudes often cannot be understood without all these measurements. Moreover, expectations as well as experience are subject to influence and change.

We are now learning what is required for successful team effort. It is possible to put this information into your models and into your training programs.

Problems in Measuring

There are problems in measuring, however. The numbers obtained are no better than the methods you use. Many pollsters and market researchers use inadequate methodology. As a consequence, important decisions are based on inaccurate results and at times this is costly experience. Instead of spending $30,000 to get accurate information, for example, research costs are cut to $15,000 and inaccurate quota sampling methods are used.

With quota samples there is no mathematical means for estimating random errors or detecting biases. In a true probability sample each person has a known probability of being contacted. Pollsters frequently randomly select a group of residences, and then talk with only those people who are at home. The people who are at home areusually those with large families. The pollsters have no way of knowing the size of error introduced by the fact that the attitudes of people with large families predominate.

Another source of error is the failure to differentiate between symptoms and casual factors. For example, if one finds from a survey in a large organization that people complain there is too little communication, chances are increasing communications will not improve the situation. One must attempt to find the causal factors, not the symptoms. You wouldn't think much of a doctor who treated the rash in scarlet fever. Production is related to good communication, but an increased emphasis on communication may not lead to an increase in production. The attitude toward communication is a function of other variables. What is more important is whether subordinates trust their supervisor and confide in him, and, also, whether he confides in them. I heard recently of a meeting of sales managers being addressed by a vice-president of research. One of the managers asked about rumors he heard about a new product. The vice-president did not duck this question but told of the new product that would not be ready for about a year. He indicated this product was a secret development. He gave the sales managers important information and indicated he trusted them to keep it confidential. Where there is distrust, where people hold their cards close to their chests and where people are trying to outdo each other, and are stabbing each other in the back, even direct communications, or an increase in communication may lead to additional mistrust. Under such conditions, subordinates tend to believe the opposite of the intent of the communication. They tend to ask themselves, "What is the boss or the company up to now?" Hence, an increase in satisfaction with communication is not necessarily brought about by more communication. More communication activity may actually create an adverse effect.

This discussion of communication illustrates the need for differentiating between symptoms and causal factors in obtaining measurements, in mathematical models and in the interpretation of results. It is especially important to make these differentiations when using attitudinal, motivational, and similar kinds of variables.

The following account* summarizes some of the steps used in interviewing studies conducted by the Survey Research Center in carrying out its human relations program.

Theoretical Development and the Formulation of Hypotheses:

Any scientific program of knowledge develops by the formulation of research hypotheses and by the testing and successive reformulation of hypotheses. Most market research which merely attempts a descriptive account of immediate problems can be continued indefinitely in time without building up any tested body of knowledge. It is important, therefore, at the very start of a research program, to set up general theories and specific hypotheses which derive from them to be tested by survey or experiment.

The initial development of theory and hypotheses in this field stems from two main sources (a) sociological and psychological theory and (b) related research studies that have been carried out. Thus it is possible on the basis of existing theoretical knowledge in social psychology to formulate hypotheses which carry further the preliminary work done in the Hawthorne Study and in the wartime studies of industrial morale.

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* This material is taken from a statement prepared by Dr. Daniel Katz

The general theoretical formulation with which the Survey Research Center started its human relations program is to be found in the paper of Rensis Likert and Daniel Katz delivered before the American Psychological Association in September, 1948.

Of the many hypotheses formulated for testing, the following four examples are typical:

(1) Group morale is not a single unified entity, but rather breaks down into a number of different types of motivation. These different types of motivation may be related, depending upon the particular situation in which they are found, but each type of motivation may derive from a different set of causal factors. Industrial morale breaks down into (a) intrinsic job satisfaction, (b) pride in work group, (c) satisfaction and identification with company, (d) satisfaction with wages and changes for promotion.

(2) Intrinsic job satisfaction is related principally to the type and nature of the work itself and not to company policy.

(3) Leadership practices which rely upon indirect methods of motivating people are more successful in achieving productivity than leadership practices which emphasize direct pressure for production.

(4) The greater the centralization of function and authority in an organization and the more all decisions are made at the highest level, the less productive and the less motivated the rank and file workers will be.

Planning the Study

After the formulation of theory and initial hypotheses there is still the problem of planning the particular study. This calls for many visits to the industrial plant or governmental agency to be studied. During these visits there is a good deal of observation of the organization at work, there are conferences with the local experts in the personnel bureau, there are detailed interviews with top management and with representatives of the many groups in the organization.

This preliminary scouting gives the necessary information for setting up a research design for a study. The research design specifies the factors on which measurements are to be taken and specifies further the controls and checks that are necessary to establish causal relationships. In other words, if we are studying the psychological causes of differences in production, the research design must rule out the possibility that the differences in production are due to technological factors. Thus work groups are compared only when the type of work they are doing is essentially similar and the technological factors affecting the work are the same.

In the first study in this program, conducted in a large insurance company, the design was worked out so that work groups differing in productivity but similar in all technical respects could be compared on worker morale and on the type of supervision and leadership in the group. The design is set up to make possible the testing of the hypotheses in a controlled manner.

The Pretest or Pilot Study

Before a full scale study is undertaken the techniques and instruments of measurement need to be pretested in a pilot study or a dry run. The pretest enables the project director to determine which questions are giving the information desired by the research design, which questions need to be modified, and what areas need new questions for adequate coverage. Sometimes a pretest will indicate that a change in some part of the research design is necessary. The pretest also serves to iron out the difficulties in the administration of the study, for example, problems of scheduling and the cooperation needed at various levels in the organization. In addition, the pretest provides an opportunity for the training of field workers and interviewers in the specific demands of the study.

A pretest will run from three days to two weeks and will involve interviews with from 30 to 200 people. After the pretest the materials obtained will be analyzed and the final study modified on the basis of the findings.

Field Work

If proper cooperation has been obtained with the group to be studied, the field work can now be started. The field work includes three types of measurements: (1) interviews with rank and file personnel, with supervisory and managerial personnel and with representatives of the union (often instead of interviews or in addition to them, questionnaires developed by means of several pretests, are administered anonymously in groups); (2) observation of the behavior of the groups being investigated and (3) the systematic collection of objective records already available, for example, figures on absenteeism, turnover, scrap loss (or error records) and productivity.

The number of people to be interviewed depends upon the design of the study and many of the studies in this program require total coverage of the groups being investigated rather than a sample. The field work involves a large staff of interviewers and observers because the interviews will require from one to three hours to be taken and will require even longer periods to be written up. The interviewing of top managerial personnel presents a special problem because the interviewers chosen for this assignment must represent an unusual level of experience, background and competence. Their recruiting is thus a long and difficult task. The field work on a study may take between two and three months for completion.

Coding and Analysis

As the interview materials are assembled they are sent to the home office for coding. In the interview situation the respondent is encouraged to tell his story in his own terms and though standard questions are employed they are not the "yes" or "no" type of fixed-alternative questions. Hence, the free answers that have been received have still to be quantified.

This is done by setting up specific dimensions and specific categories within these dimensions. The process of building codes that will fit the data and that will also meet the requirements of the research design is again a laborious and difficult procedure. When the codes have been set up, the interview materials are scaled according to these codes and reliability checks are made by having different coders make independent judgments. Then the material is punched on IBM cards to facilitate computation and analysis.

The analysis involves both a comparison of the gross frequencies of responses in the different groups and intercorrelations between the many factors as well as the building of indices. Before conclusions can be drawn on the basis of the analysis, alternative explanations have to be explored and tested. The original planning and the analysis represents the real heart of the research process and requires the most skill and the most training on the part of the personnel involved.

I hope that the material which I have briefly presented in this session illustrates adequately the important variables dealing with human behavior which you can measure and build into operation research models.

APPLICATIONS OF DYNAMIC PROGRAMMING*

George Kimball
Arthur D. Little, Inc.

The name Dynamic Programming was coined by Richard Bellman. An expository article with pertinent references to the theory of dynamic programming may be found in Reference 1. To illustrate the concepts involved in this theory, we will not start with practical applications, but will consider some simple games. A game has some of the essentials of real life, but is stripped of many complicating non-essential features.

We will start with baseball. The important thing for our discussion is that baseball consists of a sequence of plays involving situations that require decisions. For example, if a man is on first base, should he try to steal second, or should he wait for the batter to hit?

In baseball, there is a succession of situations at each of which a decision has to be made. We would like to find a fundamental way of making a best decision. Best means maximizing something. In baseball, we assume that the best strategy is to maximize the expected number of runs. This involves some simplification from real life, for in the last of the ninth inning with the team at bat trailing by a single run, scoring more than two runs is of no advantage. However, for a first approximation, we shall define the objective of the game to be to score the most runs. For convenience, we will make further simplifying assumptions. We will assume that all players have batting averages of .250.

If you set out to try to consider all of the possible decisions and try to make them all best, you get into a horribly complex situation. If we start at the beginning, we soon encounter something of the order of a million possible strategies. It is not practical to evaluate each of these. The purpose of dynamic programming is to consider single situations rather than the whole mass.

Let us now introduce the important concept of value. We want to attach a definite numerical value to each situation. If we can do this, we can assign measures to strategies. We would like to associate the expected number of runs scored with each situation. To find the expected number of runs, we must know the strategy. To avoid difficulty, we define the value of a situation to be the expected number of runs when the best strategy is used. It looks as if we have committed a circular error. We would be in a hole if we tried to do everything at once. The essence of

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* Notes taken by H. Horwitz

dynamic programming is to find two things at once -- the best strategy and the values associated with the various situations. It is characteristic of dynamic programming that one starts with late situations and works back to earlier situations.

Consider the situation where there are men on first and second with two out. It is clear that the best strategy will not be a sacrifice. Let us assume the batter will attempt to hit. Further, we make the simplifying assumption that the batter singles or makes an out. If he singles, we assume that the man on first advances to second, and that the man on second scores. Denoting the value of the situation by v_1 and recalling that a batter has a probability of 1/4 of getting a hit, we obtain the equation:

$$v_1 = 3/4\ (o) + 1/4\ (1 + v_1)$$

The $(1 + v_1)$ deriving from the fact that a run is scored at a hit and the situation obtained after a hit is exactly the same as the original one. Solving for v_1, we get $v_1 = 1/3$.

We can use this now to evaluate other situations. Let v_2 denote the value of the situation where there is a man on first with two out. Further let us assume that there is no stealing or sacrifice. Then we get the equation

$$v_2 = 3/4\ (o) + 1/4\ (v_1)$$

The appearance of v_1 deriving from the fact that a hit yields the situation previously considered. Thus

$$v_2 = 1/12$$

We can inch along in this manner until we have constructed a whole table of values for situations, these values based on the assumption that the batter is going to attempt to hit -- no stealing, no sacrifice. Then we can test the strategy using the tabulated values. For example, let the situation be a man on first and one out, the tabulated value is

.23

The tabulated value for a man on second and one out is

.51

and the value for no men on base and two out is

.021

Assuming the probability of a successful steal is 1/2, the value of a steal for the assumed situation is

$$1/2\ (.021) + 1/2\ (.51) \cong .26$$

and we come to the conclusion that the correct strategy is to steal. Now the value of the original situation becomes .26 in the table because the man on base will attempt to steal.

We must go through the table again. If we continue the process long enough and hard enough, we will finally arrive at a complete set of optimal decisions and values for the various situations.

I do not want to dwell too long on this example. Let me switch to the card game 21, sometimes called blackjack. I will consider the professional variety because the rules there are more rigid. The object of the game is to try to get as near 21 as possible without going over. The dealer is required to draw if his total is 16 or less, and stand if it is 17 or more. The probabilities of the dealer totals are

bust	.291
21	.118
20	.131
19	.178
18	.138
17	.144

To simplify the situation we shall not take into account cards visible to us in calculating probabilities. To get at the optimal strategy, we again consider sets of position values and strategies simultaneously, working backwards.

Let us assume that the bet is one dollar. Then if we go over, the value of the situation is -1. If we have 21, it is clear that the strategy is stand and its value is .882 because while the dealer will win if he ties, the probability of the dealer getting 21 is .118. To summarize

situation	value	strategy
21	.882	stand

If we have twenty, it turns out that the best strategy is to stand, and the value is .585. The method entails going down the line, and we arrive at the following strategies and values for various situations.

situation	value	strategy
bust	-1	
21	.882	stand
20	.585	"

situation		value	strategy
	19	.227	stand
	18	-.008	"
	17	-.274	"
	16	-.148	"
	15	-.178	"
	14	-.0412	draw
below	14	-.132	draw

The expected value of the gain to a player using the optimal strategies is -.0618. Let me caution you not to use these strategies in an actual game, because the strategies to be used depend upon knowledge of cards showing. In our computations we made simplifying assumptions so as to avoid elaborate computations. We could take the more complex factors into account if we wished.

Thus far we have considered games that have a definite end. Now I would like to consider games that go on and on without stop. We are looking for best in the long run strategies. What does this best in the long rur mean? To get the idea across, I would like to consider the following very simple game. The game consists of a series of moves of a checker from the positions illustrated in Figure 1.

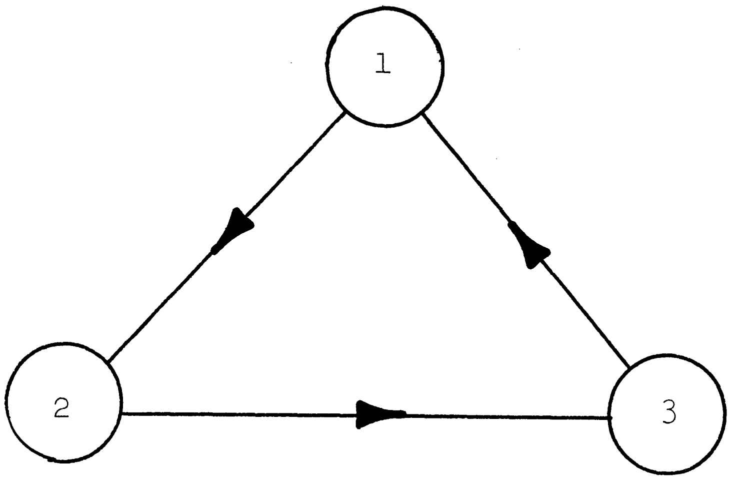

Figure 1.

At each stage of the game, the player may move one position in the direction of the arrows, or he may choose to flip a coin to select direction. If the coin falls heads, he must move in the direction of the arrow;

tails, he must move one position opposite to the arrows. Each time the checker lands at position one, the player receives nine dollars. The idea of the game is for the player to get the most money in the long run.

In order to develop some feeling, let us assume there is one move remaining in the game, work backwards, and look for a pattern. The value associated with position one prior to the last move is clearly 0 and either strategy is all right. The value associated with position two is 4.5 because the only way of getting any money is by moving opposite to the arrow and the probability of this is 1/2. The value of position three is 9.0 because the strategy is just move ahead.

Now we are in a position to compute values and strategies for next to the last move. The value of position one in this situation is obtained as follows. If we move without tossing we get position 2 which has a value just prior to the last move of 4.5. If we toss a coin we have 1/2 chance of the value 4.5 plus 1/2 chance of getting position 3 with a value of $9.00. Thus the better strategy is to toss a coin and the value associated with the next to last move is 6.75. We can continue the process and can obtain Table 1. Under the heading v_1 are listed the values of the three positions when there are i moves to go. The strategy for the position is denoted by superscripts. An asterisk indicates one should toss the coin, a 0 indicates any strategy is all right, no superscript indicates one should move directly without tossing the coin.

Position	v_1	v_2	v_3		v_{10}	v_{11}	v_{12}
1	0^0	6.75*	9.00		37.68*	41.66*	45.67*
2	4.50*	9.00^0	12.58*	...	40.68*	44.66*	48.67*
3	9.00	9.00	15.75		42.65	46.68	50.66

TABLE 1

The table indicates that the process is settling down and the expected return per move is about $4.

We can indicate the situation as follows:

Position	v_n	v_{n+1}
1	a	$a + G_1$
2	$a + v_1$	$a + v_1 + G_1$
3	$a + v_2$	$a + v_2 + G_1$

TABLE II

It can be proved, under moderately general assumptions, that games of this sort do settle down although it may take a long time to occur. In using the process we do not need to know a or G_1, but need only v_1 and v_2. We can use the known form of the solution to estimate what the values are. We obtain the equations

$$G_1 = 1/2\ (v_1 + v_2)$$

$$G_1 + v_1 = 1/2\ (v_2 + 9)$$

$$G_1 + v_2 = 9$$

which yield

$$G_1 = 4$$

$$v_1 = 3$$

$$v_2 = 5$$

for the assumed strategy.

We now can feed back into the various situations and test. If it is right, we do nothing; if it is wrong, we change values and strategies. The process usually converges quite rapidly.

What do we look for in problems to determine if dynamic programming applies? The following are some of the characteristics:

1) Set of situations

2) Sequence of moves from one to other situations

3) Cost and rewards (negative costs) are associated with the moves

4) Decisions associated with chance moves.

5) Object is to find best way of making a decision for each situation.

I now turn to some practical applications. In a paper mill, the paper is laid on a large and expensive screen in the machine. These screens wear out and must be replaced. The mill works 24 hours a day and is closed Sundays. Sunday closings permit changing the screens. If the screen breaks down during the week, a large fraction of the day's production for the machine is lost. The basic problem is: If the screen has been on x days, shall we take it off or leave it on and consider it again on the following Saturday night?

This problem is typical of a large class of maintenance problems. One needs statistical data; in this case one must construct a mortality table of the life of a screen. It was fortunate that the mills in question had been keeping good records of this. To solve the problem, we can attach values to any screen which has been on any number of days. The right decision leads to a maximum value the following week. A typical solution turns out to be: If the screen has been on less than 5 days, leave on; otherwise, change.

Another problem pertains to hotels. The hotel keeper gets reservations for rooms, sometimes a month in advance. With time he gets added reservations and cancellations. When should he accept and reject reservations? It is obvious that the answer is not just to book the number of rooms he has. On the other hand, he runs a risk in overbooking if cancellations do not turn up. It is very difficult to determine the cost of overbooking. Fortunately it turns out that the solution to the problem is not sensitive to this cost. The technique for handling the problem is again the same. To solve it we need to know the cost of overbooking and the statistics of reservations and cancellations.

Another problem we worked on was closely related to the one above. It had to do with airplane parts -- expensive ones. We had to find the best place to keep them so that they would be available when needed. Involved in this problem are the costs of delay and transportation. A similar problem concerns empty cabs -- should they stand or move? The techniques for handling these problems is again the same -- generating sets of values and strategies.

Another problem still in the same area concerns the distribution of sales effort. In a particular company, salesmen could call on customers or prospective customers in various numbers of classes (categories). The total time of the salesman is limited. After completing a call, whom should he call on next? To solve, we must have information for each customer and prospective customer class relating to the expected return of a sales call. The method of solution is still basically the same.

There remains the whole problem of production scheduling and inventory control. This is definitely a problem which falls within the scope of dynamic programming. Here we encounter a complicated system of states, stochastic elements, and a wide variety of costs. The costs are direct accounting costs, capital tied up in inventory, and service failure. Time limitations preclude discussing this problem fully or going into the problem of training.

What is important is that one can solve problems by setting values for each situation and decision associated with the situation. If one doesn't use some such method, he becomes too concerned with immediate returns. It is not necessary, or even desirable, to shoot at once for the ideal solution. Unless policy is perfect, improvement shows up, and it is preferable to move toward the best policy without too many changes at once.

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1) Bellman, R., "Some Aspects of the Theory of Dynamic Programming -- A Review", Journal of the Operations Research Society of America, August, 1954.

ORGANIZATION THEORY APPLIED TO THE FIRM*

Jacob Marschak
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The firm may be considered from two essentially different aspects. The first view contends that the presence of human action and decision allows only for description and classification. The second view contends that the firm has a definable objective or task and can be viewed from a normative analytical standpoint, in the spirit of Operations Research. However, parameters describing human behavior in the firm are needed; they may be supplied by work such as Likert's. The approach below was given impetus by classical economic theory of the firm and the newer theories of statistical decision functions and of games. The talk will have three main headings:

1. The organization rule

2. Single men decisions

3. The team

Organization Rules

The present organization manuals are rather difficult for the Operations Research man to read. The current organization charts tell only the supervisory relations within the organization. What is needed is a description of the "decision functions" that determine the individual's responses to information. Consider the following matrix:

	0	1	2	3
0				
1				
2				
3				

0: outside world
1, 2, 3: individual in firm

* Notes taken by Richard Legault

The row labeled 2 represents messages sent by individual 2. The column labeled 2 represents the messages received by him. An entry in row 2, column 0 represents the "message" of individual 2 to the outside world; this includes his physical actions. The diagonal entries (for example, the cell in row 2, column 2) represent the memory of the individual 2.

Now make the matrix a function of time. The row $a_2(t)$ would represent the output of individual 2 at time t. The column $a_2(t)$ represents the input of individual 2 at time t. The entry in column 1, row 2 at time t represents the message received by individual 1 from individual 2 at time t.

An organization rule, say, R_2, relates the messages sent at one time to those received at an earlier time, for individual 2:

$$a_2(t) \quad = \quad R_2[a_1'(t - 1)]$$

For example, the rule R_2 may say that if individual 2 receives an input from the outside world at time t - 1, he gives out an output at time t to individual 1. In short, the rule R_2 relates the input of individual 2 at time t - 1 to the output of individual 2 at time t. The set of rules, $(R_1, \ldots, R_n)$, in essence represents the organization of the firm with respect to the "roles" or "functions" of the individuals of the firm.

Single-Man Decision

We shall now proceed to give an analytic model of the decision process in a one-man firm. On Chart 1, circles indicate variables, and boxes indicate "operators," ("function"); in the accompanying mathematical notation, Latin letters denote variables, Greek letters denote functions.

The outside world has an input to the firm. This input may be the level of the price of raw materials or the price of the firm's product in the market place. Information about the state of the world is gathered by the firm. The firm need not obtain a complete picture of the world. It uses an "information filter," η. This filter may be a sampling plan such as is used in statistical quality control or a commodity list as employed by the Federal Government to measure the so-called price index. The output of this filter is the "information": a variable $y \; = \; \eta(x)$.

Once the firm has received information about the true state of the world some action is taken. This action will result from applying some "rule of action" to the information y. The action rule is represented analytically as a function α. Thus, $a = \alpha(y)$. For example, the price index may be used by a firm to decide whether to buy or sell a commodity. Thus, a relation between the information received and filtered by the firm and the action taken has been determined.

The outcome of the action must be described next. This outcome, or payoff, u, will, of course, depend on the action taken, a, and on the true state of the world, x. This outcome is represented analytically by the payoff function, $\omega(a, x) = u$.

This "gross" payoff must be reduced by the cost of information and of decision-making. The cost of information and decision is given by the function, $\gamma(a, \eta)$. Subtracting the cost from the gross payoff, we have the net payoff, $\omega(a, x) - \gamma(a, \eta)$. The states of the world can be regarded as chance or random occurrences. The probability of occurrence for a state of the world is given by $\pi(x)$.

The expected net payoff is, therefore,

$$V(a, \eta) = E[\omega(a, x) - \gamma(a, \eta)] = \sum_{x} \pi(x)[\omega(\alpha(\eta(x)), x) - \gamma(\alpha, \eta)]$$

The desire of the operation researcher is to maximize $V(\alpha, \eta)$ with respect to α, η, i.e., to choose a rule of action and an information filter that are best in the long run.

Example A

The example below is from production. There is only one input (factor of production) with diminishing marginal contribution to the total production; it may be labor or raw material or some mixture of the two in a constant proportion.

Let a = input, f(a) = output. Assume decreasing marginal returns (i.e., second derivative $f'' > 0$) and approximate f by a quadratic function. Assume the output price to be constant, but the input price to be a random variable whose deviation from its mean will be denoted by x. Hence, the expected (average) input price = Ex = 0. We can choose the units of input and output, and the origin for a, in such a way as to write the profit as

$$u = - a^2 - ax + p_o + px,$$

where p_0 and p are constants. When $x = 0$ (i.e., the input price is at its average level), the profit-maximizing input equals zero, yielding a profit p_0. This is then the meaning of the origin (a "normal input") from which we measure input, and of the constant, p_0. Now consider two alternative information filters:

η_1: the producer always gets information about current input price;

η_2: the producer knows only the average price.

In the first case, the best action rule is clearly: $a = -\frac{x}{2}$, yielding a maximum profit $\frac{x^2}{4} + p_0$. In this case, the maximum <u>expected</u> profit is $\frac{\sigma^2}{4} + p_0$, where σ^2 is the variance of the input price. In the second case, the best input will be a constant (we then have "routine administration"!): the producer will maximize expected profit $- a^2 + p_0$ by always keeping input at its "normal level" ($a = 0$); he will obtain on the average a profit p_0. The average advantage of using more information (filter η_1 rather than η_2) equals $\frac{\sigma^2}{4}$: it is proportional to the variance of price. If the cost of current price information is less than $\frac{\sigma^2}{4}$, the filter η_1 should be used; if it is more than $\frac{\sigma^2}{4}$, the filter η_2 is preferable.

The Team

The model of the organization described in the preceding section can be generalized to more than one individual. The information filter η can be regarded as a vector $(\eta_1, \ldots, \eta_m)$, where there is one filter for every individual in the team. Then the information y is replaced by a vector $(y_1, \ldots, y_m) = [\eta_1(x), \ldots, \eta_m(x)]$. In a similar fashion, the action rule is replaced by a vector of action rules, $(\alpha_1, \ldots, \alpha_m)$. The vector of information filters and action rules represents, in fact, the organization rule discussed above. As we can see, the rule specifies what kind of information becomes available to each member of the team and how he responds to it. The organization rule will have a cost. This cost is subtracted to compute the expected net payoff of Chart 1. The purpose of analysis is to maximize the expected net profit with respect to the $(\alpha_1, \ldots, \alpha_m)$, $(\eta_1, \ldots, \eta_m)$. The example below will give the reader some insight into the suggested model.

Example B - Production of a Single Commodity by Two Partners

The example is the production of a single commodity with two inputs, each controlled by one partner; we assume again a quadratic production function, and output price constant.

Levels of inputs:	a_1, a_2
Prices of inputs:	x_1, x_2
Production function:	$B - a_1^2 - a_2^2 + 2qa_1a_2$ + a constant. We also assume: $q^2 < 1$. (This guarantees the existence of profit maximum at finite inputs.)
Total cost of input:	$a_1x_1 + a_2x_2$

By suitable choice of units and origins, profit can be written

$$u(a, x) = B - (a_1^2 - 2qa_1a_2 + a_2^2) - (a_1x_1 + a_2x_2)$$

with B a linear function of x_1 and x_2; x_i, deviation of price from mean (hence, $Ex_i = 0$); a_i, deviation from level which is best when each $x_i = 0$. Let Ex_1^2 Ex_2^2, and choose money unit to make $Ex_1^2 = 1$. Write $Ex_2^2 = \rho\tau$. Assume x_1, x_2 to have joint normal distribution. To compute the expected gross payoff or a given information filter, one must first derive the best action rule for each partner, from the following consideration: each partner should try to maximize the conditional expected profit, given his information. The results will depend on the following three parameters:

$Q = \dfrac{\partial^2 u}{\partial a_1 \partial a_2}$, a measure of positive (negative, zero) interaction between two inputs in production;

τ = a measure of the ratio of uncertainties about the two prices; and

ρ = coefficient of correlation between prices.

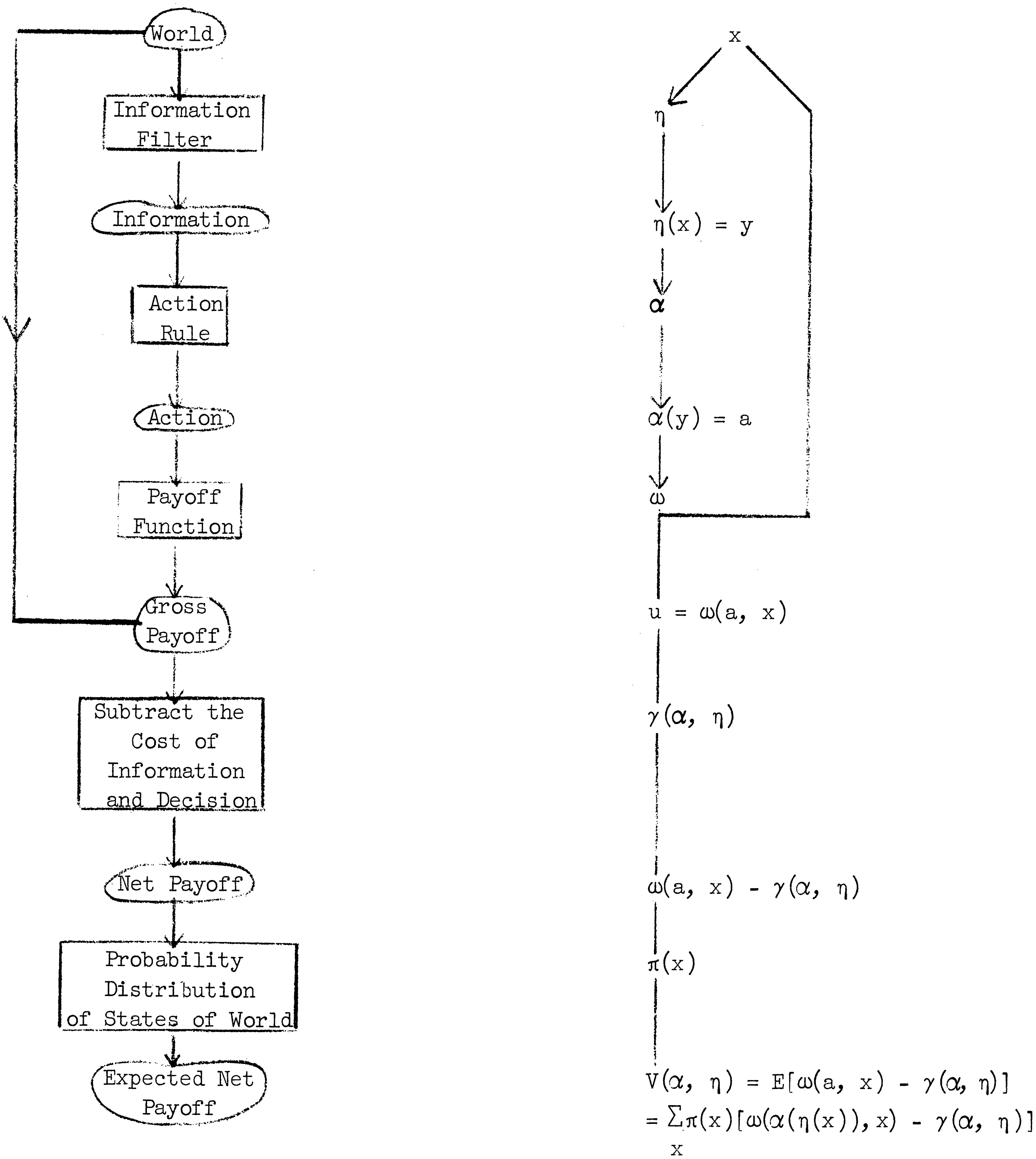
An information filter will be defined by "who knows what." Each partner can know one of four things about current input prices: (1) nothing; (2) x_1; (3) x_2; (4) x_1 and x_2. Hence, there are altogether $2^4 = 16$ possible filters. We can assume that the i-th price is always learned at a smaller cost by the person deciding about the i-th input than by the other person. Then it turns out that, using optimal decision functions, only nine structures have net expected payoffs that are not dominated (for all values of parameters) by those of some other structures. The best gross expected payoffs of all16 filters are given in Chart 2, where, for example, the column heading (10) means that the first input is decided on the basis of the knowledge of the first but not of the second price; row headings refer correspondingly to the second input. Cells corresponding to the non-admissible (dominated) structures are crossed out. The remaining, i.e., admissible, cells contain, in addition to the maximum expected gross payoff, symbols for the network that generates the given structure, in the following notations: a square, □, means "n observation," x means "observation," and arrow means the direction of communication. The left (right) place corresponds to the person deciding about the level of the first (second) input and possibly observing its price. Thus, x → □ means: first price is observed by the first and communicated to the second person; second price not observed.

How do the parameters q, ρ, τ influence the choice of the best network, given the cost of observing and communications the current values of x_1 and x_2 ? The effect of variance was already discussed in Example A; we may conjecture that the larger t, the larger the advantage of, say, □ ← x over x → □ . If we assume the two variances equal (τ = 1), two such networks become equally good. This symmetry assumption reduces the number of networks to be considered to six; and the number of parameters to two (q and ρ), and we can draw a two-dimensional diagram showing, for fixed levels of observation and communication costs, the regions of the (q, ρ) plane in which each network is best. Such a diagram is drawn on Chart 3. One sees how the need for more communication is great when the absolute value of integration is great and the absolute value of correlation is small. This is what one should have expected intuitively; but other details of the diagram are not easily derived from mere "common sense."

CHART 1

DIAGRAM FOR DECISION PROCESS

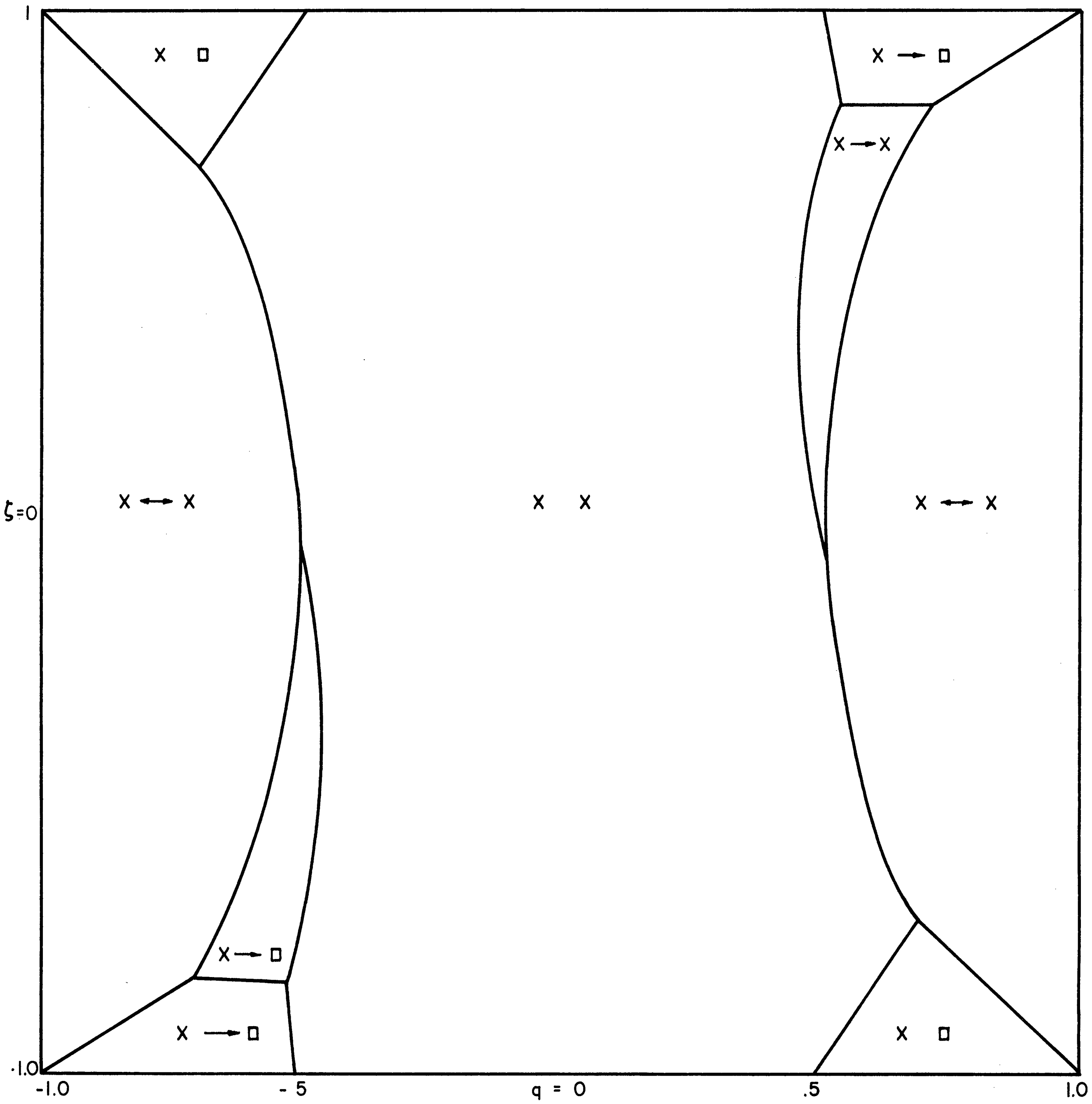
SINGLE MAN



α_2 \ α_1	(00)	(01)	(10)	(11)
(00)	0 □ □	ρ^2	1 x □	1
(10)	$\rho^2 \quad \tau^2$	$\frac{\rho^2(1 + 2\rho\tau q + \tau^2)}{1 - \rho^2 q^2}$	$\frac{1 + 2\rho\tau q + \rho^2\tau^2}{1 - q^2}$ x → □	$\frac{1 + 2\rho\tau q + \rho^2\tau^2}{1 - q^2}$
(01)	τ^2 □ x	$\frac{\rho^2 + 2\rho\tau q + \tau^2}{1 - q^2}$ □ ← x	$\frac{1 + 2\rho\tau q + \tau^2}{1 - \rho^2 q^2}$ x x	$\frac{1+2\rho\tau q+\tau^2-q^2(1-\rho^2)}{1 - q^2}$ x ← x
(11)	τ^2	$\frac{\rho^2 + 2\rho\tau q + \tau^2}{1 - q^2}$	$\frac{1+2\rho\tau q+\tau^2-q^2\tau^2(1-\rho^2)}{1 - q^2}$ x → x	$\frac{1 + 2\rho\tau q + \tau^2}{1 - q^2}$ x ↔ x

CHART 2. Example B: Best expected gross payoff for all information filters. The corresponding network is indicated for the nine admissible filters.

CHART 3



OPERATIONS RESEARCH IN JAPAN*

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If I would talk to you on Operations Research in Japan I would simply say that it is non-existent and ask for questions. However, I will try to tell you something about the things which we saw on a recent trip and the possibilities which I see for OR in Asia. In connection with the work we are doing at Waseda University in Japan I have just returned from a trip around the world on which I visited eighteen countries including India, Japan, the Philippines, Indonesia and Thailand. Outside of these countries the others are small with practically no resources and it does not seem that they can ever develop within their present boundaries into groups of great consequence. There are, of course, in some of them many good sized industries such as the rubber industry in Malay. I do not mean to say that these smaller countries will not be good places, for a country such as Thailand has fine people, is self sufficient and they can live very nicely but there does not seem to be the possibility to do any large building of industry. Of the other countries India and Japan present the best possibilities for Operations Research, although the Philippines, Indonesia and Thailand may at some time also offer possibilities.

I am not going to give a definition of Operations Research but for the purpose of this talk will say only that there is the means to a way of doing things better, more efficiently and cheaper, or the means to produce more and create markets through better decisions. In the United States we have a large educated middle class while these countries which I have visited have in general only a small highly educated class and a large non-educated class. This is one of the reasons why OR can offer so much for us and so little for these countries. We cannot say to these people "do the same as in the United States" as the conditions are too different. Too many of the people who go out of the United States to these other countries want to try to make them the same as we are in a short time. They tell the uneducated people how we do these things and make them feel they should have everything. Naturally it is impossible for such a tremendous change to take place in a short time so the people become dissatisfied. It seems obviously impossible to expect these countries to go all the way quickly. However, they can accomplish what we have if they are educated and their standard of living is gradually built up. We can do more in education than any other way. If too much is tried to be done all at once such countries will be ruined.

In order to understand this, I will explain to you how some things are done. One of the things which I learned is that if you have enough people and enough baskets you can accomplish anything. We have a great many illustrations of this in the old ruins in such places as Lebanon, Egypt, Rome and so forth. I will give you an illustration of making a fill for a roadway in India. . A new bridge had been built across a river and to connect it to the old roadway it was necessary to build a fill about twenty feet wide and four or five feet high from the end of the bridge to the old road, probably 200 yards long. To do this job each family had a small plot of land which they were to dig and move the dirt to the fill. The father had one utensil similar to a mattock or a heavy hoe. With this he dug the ground loose, then the children scraped the ground with their hands into the basket and then either the mother or father put the basket on their heads and carried it to the fill. At first sight it seemed impossible that the job would ever be accomplished but when we came back two days later the fill was complete. I don't know many people were working on this job but there were several thousand. Each man is paid 60 cents a day, each woman 40 cents and each child 21 cents, but in addition to this guaranteed wage there was an incentive plan; every so often in the diggings there was a pillar left to show the original height of the ground. By measuring across the top of these the amount of dirt which had been moved by each family could be determined and the family was paid more than the stated rates if they moved more than an average amount of earth.

An American operations researcher or almost any engineer might be tempted to go in with large dirt-moving machinery and do this job more rapidly. One of our power-scrapers would put a tremendous number of people out of work and create an economic crisis. You simply cannot have an industrial revolution over night. If you will look back in the history of our own country you will see that this change of the industrial type processes was quite gradual, but too many people expect it to be very fast in these other countries.

Many of the roads in India are covered with a type of macadam similar to that which we use here and they are subject to the same small straight-sided holes that we have. I saw two men go up the road a quarter of a mile or so, tie a rope around a rock, put a pole between their shoulders with a rope tied to it and carry a rock to a hole in the road. There women with hammers split the rock and pounded it into small pieces and put these pieces in the hole. Then somebody with some sand in a basket on their head came along and put the sand between the pieces of gravel. Next from somewhere up the road two men came with tar in a Standard Oil kerosene can slung on a pole between them and poured tar on the sand and gravel. Then a man, or sometimes two men, squatted on their haunches and brushed sand back and forth across the tar until it became hard and the hole was filled and smooth with the top of the roadway. I could give you many more examples of the use of this low cost labor for things which are mechanized in this country. For example, to irrigate the fields, water is necessary and this must be pumped up, either from the river or a shallow well. One way of doing this is to have a large wheel with buckets fastened on the side of it. As the wheel goes around these buckets dip into the water, bring it up and dump it into a trough which delivers it to the field. This wheel is on a shaft which leads over to a gear and is in turn connected to a wheel with a pole to which oxen are attached. As the oxen go round and round the wheel turns and the water comes into the ditch. I made a quite careful approximation of the amount of water and the height to which it was lifted and found that this whole outfit with a boy, a man and four oxen accomplished work equal to one-third horsepower. Another example of getting water for the fields is a process in which two water buffalo are used to lift a skin-bag full of water from the well. A large hole is dug in the ground and dirt from it piled so that a long slope is available for the buffalo to go down as they pull up the water. At the top of the slope is a structure with a pulley. As the buffalo go down the hill they pull up a skin-bag full of water. When it reaches the top and is dumped on a platform the skin-bag collapses and about 85 percent of the water runs into a flume which carries it to the field and about 15 percent of the water falls back into the well. This operation produces more water than the other but it takes four buffalo and three men, and the total work accomplished is about one horsepower.

We saw one operation where the juice was squeezed out of sugar cane and then boiled into cakes of sugar. There were two grinding wheels set vertically in the ground and connected with gears. A long tree was fastened to one of the gears and two oxen at the end of this pulled it around and around. A woman fed one piece of sugar cane at a time between the grinding wheels and when the juice ran out it dribbled across the ground into can. Of course lots of others things also got into the can but that did not bother them. Perhaps the cooking process purified the end result. This arrangement for squeezing the cane required one woman, two men and four oxen, and only one horsepower of useful work was realized. In this total process the whole family took part. During the growing season they lived in the village and came out to work the fields. When it became time to harvest the sugar cane they moved out to huts made of grass and leaves in the field. Every member of the family was there from the oldest grandfather down to the youngest grandchild. Of course they had with them their carts, their oxen, etc. Nobody worked too hard and they all seemed very happy. It was a nice sociable affair. Again let me say there is great question in my mind as to how fast you should change some of these things. I think that first you have to create some wants among the people. These people live reasonably well and they do not seem to have great wants or desires to increase their standard of living. Of course with those who are starving it is a different situation.

Additional examples of the use of human power are the rickshaws in Pakistan and India and the pedibikes in Burma, Thailand and Indonesia. Any of these jobs could be done by machinery but as stated before this would put a lot of people out of work very suddenly. The big question is how to do any mechanization slowly enough so as not to disrupt the economy.

Japan and Germany seem to be very much alike and quite different from any other countries we have visited. In these two countries the people are industrious, studious and have a good technical "know how". I was very glad to be able to visit Japan for a second time and study more carefully many things which I had only the least opportunity of seeing before. Japan has some very fine industrial facilities. Their shipyards are excellent, and they actually turn out more ships faster than any other country. I notice from recent statistics that Japan has passed all other countries in the world in volume of ship building. I was not as well impressed with their heavy machinery plants.

I had an opportunity twice to visit one of their automobile factories and they do a pretty good job. In this plant, wage incentives were tri for one of the first times in Japan and a thirty percent increase in output was the result. They have also put in some new processes like ours such as continuous assembly lines. However, there are some interesting things happening. As were were going through the plant I saw a lot of people around some benches near the engine assembly. I asked what they were doing and the manager was rather reluctant to go over there but I insisted. Then they told me that these people were fitting the big pistons into the big holes and the little pistons in the little holes. They said their equipment was more than thirty years old and that the boring machine did not always make the same size holes and neither did the piston turning machine make the same size pistons. Therefore they matched them up along with the piston rings. When they saw that I did not understand why they should do this, they showed me some figures proving that it was much cheaper to do it this way and it keeps a lot of people busy. According to their figures it is cheaper to use labor this way than to spend money for capital equipment.

We also visited an electronics plant. We found that they do very well in some phases of work but the tolerances on some of the products were very wide. They use a lot of people to match parts but do very well in creating a useable final assembly.

However, they are now thinking about selling individual units for replacement or for other electronic uses. I asked them how they could expect to sell parts having such wide tolerances as I was sure they would not be acceptable. They said they had thought about that and they were going to sell the ones with narrow tolerances. In other words, their plan was that they would sort out the ones with the least variations and sell them as separate items and then use those with the wide tolerances in their own operations.

I have been asked to give my impressions of Japanese industry. In general, Japan has a high level of technical knowledge and has done some very good technical development. This is evidenced by the manufacture of such things as optical lens, transistors, capacitors, printed circuits, ships welding, and many things of that kind. The industries have good physical equipment and facilities for research. Their laboratories are equipped with oscilloscopes, x-rays, electronic micrometers, optical comparators and other things of this type.

I would say that the Japanese have good product design and reasonably good design of the equipment. Textile equipment and machine tools are very good. And we are all familiar with their products such as cameras, binoculars, radios, TV's and so forth.

On the other hand, many of their industrial plants and businesses are poorly housed. Most of the plant housing is made up of a lot of small area buildings which are interconnected in a random way. There are frequently many levels between buildings. One finds nonproductive operations mixed in with productive operations. Apparently there has been no general overall planning because even though buildings were built in small units at a time, if there had been an overall plan the results would have been much better than what one generally sees. Lighting, safety measure and building maintenance are poor by our standards. Material handling is largely done by manual labor, but we must remember that the reasons for many of these things is because of the cheapness of labor in Japan. And for their present conditions their methods may be more economical than ours. I am not saying that this is the way things should be, but we must admit that in many cases their methods are fitted to their conditions.

Labor unions were introduced at the time of the American Occupation and this has not helped the situation. Ordinarily there is a spring and fall labor offensive with associated strikes and with a primary aim of obtaining wage increases.

Wages in general are fixed on a subsistence level and a large bonus is given at the end of the year with no relation to production. The problem of over-population in Japan is aggravated by the fact that the workers receive a $5.00 wage increase for each child. There are very few incentives for doing more or better work. Personnel policies are all mixed up according to our standards. They are based largely on custom and tradition and the fact that there is an excessive labor supply. In order to progress properly personnel policies must follow technical advances where now they are based on tradition and custom. This stops progress. There is almost a guaranteed wage plan or perhaps better a guaranteed job. Each man once hired is practically on the payroll for life, not because of any social ideas but because the employer would lose face if he laid him off. Such management practices naturally often offset the technical achievements. Most good jobs are obtained by connections, such as University or family, rather than by training in managerial skills.

Organizational structures are different from ours. Major officers do minor jobs and minor officers do major jobs. Reporting procedures are not well established. For example, there are instances in which someone way down the line reports to the President while personnel much higher up would report to a minor official. There were cases where purchasing was done under supervision of a minor official and the problems arising from this were sufficient to nullify many of the benefits of high technical knowledge and product design.

On the other side of the picture I would say that most of the managements are alert and anxious to improve conditions, but that they were balked by customs. In some cases management also seemed unaware of its weaknesses. One of these seems to be the very subordinate position of middle management. There is also another thing which I think hampers these management relations, and that is the class system where people down the line do not dare to criticize their superiors or even offer suggestions.

You will see that all these things involve human relations, and in human relations the Japanese are bound by traditions and customs so this end of their operations has not advanced as fast as their technical development. There seems to be very little delegation of duties or decisions and part of this may be due to the almost complete lack of staff services. Without the benefit of staff analysis the top men in the organizations are not able to make decisions on the best information. The top men just don't have time to do all these things so they are done by other officials who obviously do not have the experience. This is also true of such things as market analysis and other general functions. In summary the technical ability of the Japanese is very good but management needs a lot of revamping.

This provides a great opportunity for business and universities to get together, but at present they are just as far apart as the two poles. Neither one seems to know that the other exists. A type of program to change and improve this relationship is what the University of Michigan and Waseda are working on. Waseda is a private university with about 34,000 students and practically all schools and colleges except medical. They have set up an Institute for Research in Productivity, and the University of Michigan, with the financial support of the ICA is helping them get this under way. At the present time Michigan has two people, Professor Page and Professor Gordy, at Waseda and this summer an additional man, Professor Elgass, will go there for two years. These men are specialists in Industrial Engineering and Business Administration. They do not teach but are acting as consultants to show business and industry how to work with the University and to show the University how to work with business and industry. In addition to our work there, we are training some of their people here at Michigan. At the present time eleven Japanese professors associated with the program are in the United States. Twenty more will come here next year and about eighteen more the following year.

Considerable progress in the IRP program has already been made. There are quite a number of research projects in operation and one contract has been made for sponsored research with an industry. We believe this is the first one of that type in Japan. Professor Gordy has done quite a number of plant audits which have been well received. In other words, as one man said, we are trying to show the Japanese what makes things tick here in the relationships between universities and industries.

The language barrier is naturally a formidable obstacle in this whole program. However, we are learning, both in Japan and in the United States, and I am sure that before the two year contract is up the project will be brought to a successful conclusion.

Operations Research has been studied in the universities. The Japanese are terrific readers and I imagine that at Waseda University they have read everything written in this country about Operations Research. This summer a team of four men is going from Michigan to give two OR Seminars in Japan. Plans are also being made to give similar seminars in marketing, business administration and some industrial engineering subjects. One of the problems is that between the present Japanese theoretical studies and our more practical approach to these management sciences, there is a big gap. They are trying to jump this too fast, but it makes for an interesting situation.

I have been asked to say something about differences in engineering standards at Waseda and those at United States universities. It is very difficult to make any comparisons as their teaching of engineering is much different from ours. Most of the work in Japan is of a theoretical nature and most of the time is spent in learning from books. The teaching is good and the students work very hard and spend much longer time in classes than our students do. I understand that many of the students are in classes from eight o'clock in the morning until five-fifteen in the evening, six days a week with only fifteen minutes for lunch. Laboratories are well equipped and the undergraduate work is very similar to ours. However, it seems to me there is a lack of graduate work. In conclusion, let me say though, that the Japanese turn out a lot of very smart engineers.

SCHEDULING IN JOB-SHOP TYPE PRODUCTION

Andrew Vazsonyi
The Ramo-Wooldridge Corporation

During the last few years, considerable effort has been expended in developing new scientific methods for the scheduling of manufacturing operations. This effort is well warranted, since the productivity of industrial organizations is intimately connected with the ability of scheduling production efficiently. In spite of the fact that a great deal of effort has been expended and important progress has been made in this field, it is still fair to say that no general theory of production scheduling has been developed so far. Most of the work applies to a restricted area of scheduling and does not have universal applicability. The paper we are to describe here is of the same nature. It has been successful in a particular type of production operation, and it is believed to have wide applicability. It does not have universal applicability, and it does not present a general theory of production scheduling.

The scheduling problem of the Accessories Division of Thompson Products, Inc., is a problem in scheduling of a job-lot type of production. There are hundreds of different types of articles manufactured and kept in inventory, and the principal problem is to determine what articles should be manufactured at what times, in what quantities, and on what machines. The problem is further complicated by the fact that many months of lead times must be allowed and sales requirements frequently change.

As the profit position of this industrial organization is seriously affected by the ability to schedule efficiently, it was natural to initiate a search for a better scheduling system. In particular, utilization of large-scale electronic computers, and the introduction of new scientific principles of scheduling were envisioned as leading to improvements.

In order to describe the work that has been conducted, one could take two alternative approaches. One could describe in detail the work as it has been conducted at Thompson Products, or one could present results in a generalized fashion. The first approach has the advantage that it can be very factual and specific. However, the second approach of describing the method in a generalized form has the advantage that it implicitly suggests the applicability to other production control problems. This is the reason that we select this second approach and describe the scheduling system developed in terms of the job-shop type scheduling problem faced by a hypothetical firm.

We begin this paper by a generalized statement of the problem of scheduling in job-shop type production. Then we describe the decision rules that have been developed to solve the problem of scheduling and, in particular, we describe the Time Assignment Scheduling System that has been introduced in Thompson Products. Finally, we briefly describe our current plans for the development of an optimum scheduling system based on the applications of the Monte Carlo method.

Statement of the Problem

A company is engaged in manufacturing hundreds of different types of assemblies. A highly simplified gozinto graph for one of these assemblies is shown in Figure 1.* For instance, Figure 1 shows that the particular finished product A_3 is assembled from four different articles, A_5, A_4, A_7, and A_{11}. Some of these articles are assemblies themselves, others are fabricated parts.

The articles are manufactured against sales orders that are considered firm. Some of the articles (e.g., finished articles) are manufactured on assembly lines; other articles are manufactured either on assembly lines or in a job-shop type operation. The articles are manufactured in various lot sizes. (There are only a few articles that are manufactured on a continuous line-flow type of operation; most of the articles are manufactured in lots, in a cyclic fashion.)

At the time we started our work, there was a wide-spread desire for improvements in production control. It was felt that parts were not manufactured in best quantities and not at the best times. There was a feeling--as so often is the case--that it should be possible to do better. Planning techniques were inadequate to predict machine load bottlenecks. Confidence in machine-prepared production control reports was limited, and decisions based on these

* For a detailed description of the concept of gozinto graphs, see A. Vazsonyi, "The Use of Mathematics in Production and Inventory Control," Management Science 1, pp. 70-85, 207-223 (1954-1955).

GOZINTO GRAPH

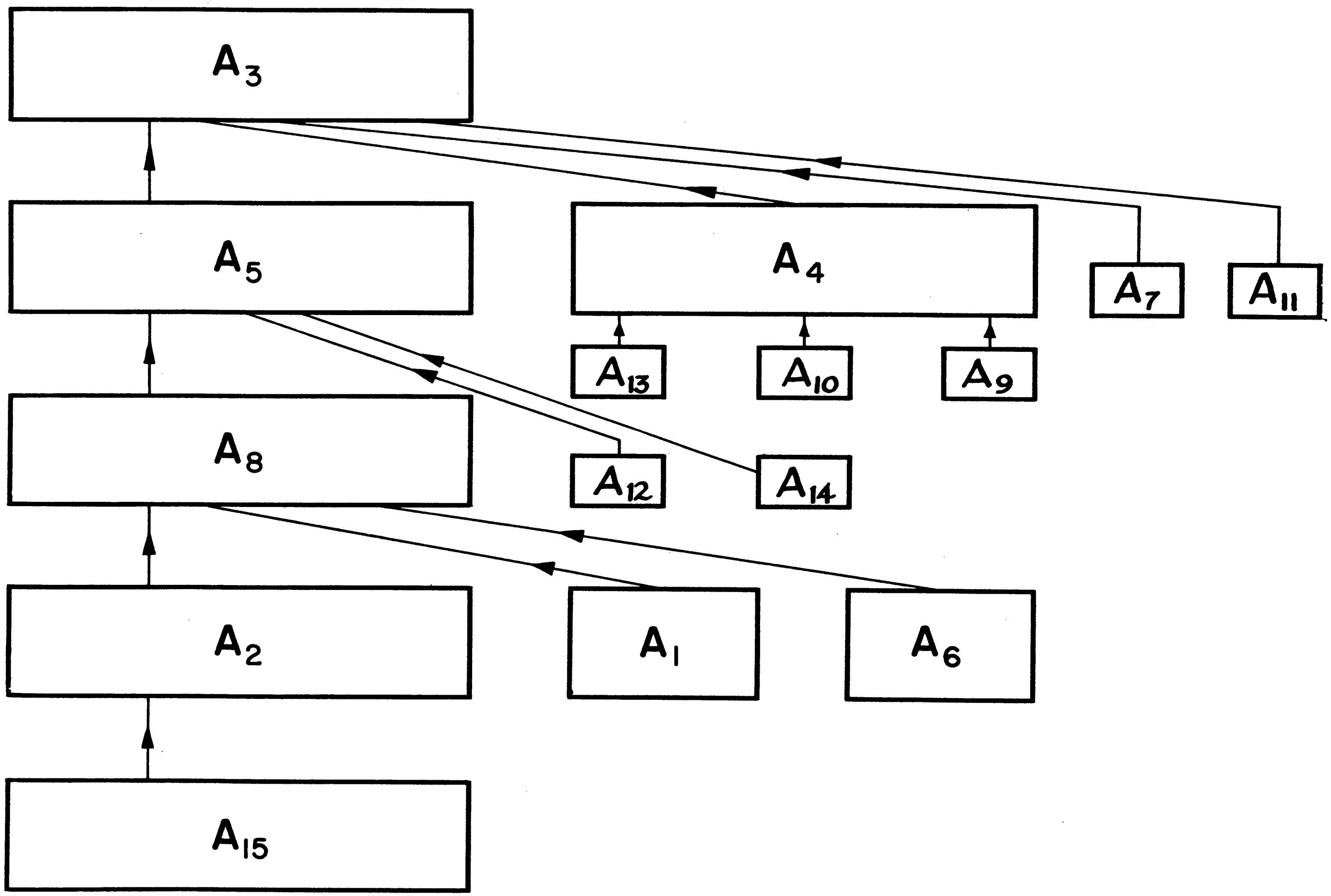

FIG. 1

reports were questioned. There was a need to make the production control reports accurate and timely, but more important there was a need for improved, explicit decision rules.

In order to appreciate the complexity of the production problem let us consider Figure 2 where a historical record of a hypothetical production situation is described. The horizontal axis describes time in manufacturing days and hours. We distinguish between four labor classes, each of them referring to a particular machine or machine group. Ω^3_1, $\Omega^3_{1,2}$, $\Omega^3_{1,3}$ describes three successive operations of the third lot of A_1. It can be seen that the first operation on this particular lot is to be performed on the first group of machines. After this operation is completed, the semi-finished lot is transported to the third group of machines where the second operation is performed. Finally, the lot is transported to the second group of machines, where the third (or final) operation is performed. This means that at that point the third lot of A_1 is completed. Similarly, one can follow the production of the first lot of A_3. $\Omega^1_{3,1}$ describes the first operation on this lot; this is performed on the fourth group of machines. The second operation on this lot should be performed on machine group 3; however, because of interference, that is, because of the fact that this machine is busy manufacturing A_1 and A_2, we have to wait before the second operation $\Omega^1_{3,2}$ can be performed. $\Omega^1_{3,3}$ shows the third or final operation on this lot.

In many manufacturing firms it is customary to prepare charts in advance, similar to the one shown in Figure 2, and use them for planning purposes. One begins by setting up the shipping dates and then works "backwards." A complete chart for the future is prepared. Every time a certain operation is completed, the foreman consults the charts and determines what particular lot should be worked upon. If the lot is not available, he knows that the lot is late and he takes corrective measures.

In the specific case under discussion, it was considered impractical to follow this sort of planning scheme. There are hundreds of shippable items involved and thousands of parts manufactured and purchased. The possible number of combinations in this "jig-saw puzzle" are astronomical. Preparation of even a single chart of this type would be an exceedingly time-consuming job, but even then there would be no assurance that the first try is an efficient one. There is, however, a further difficulty.

SHOP — LOADING

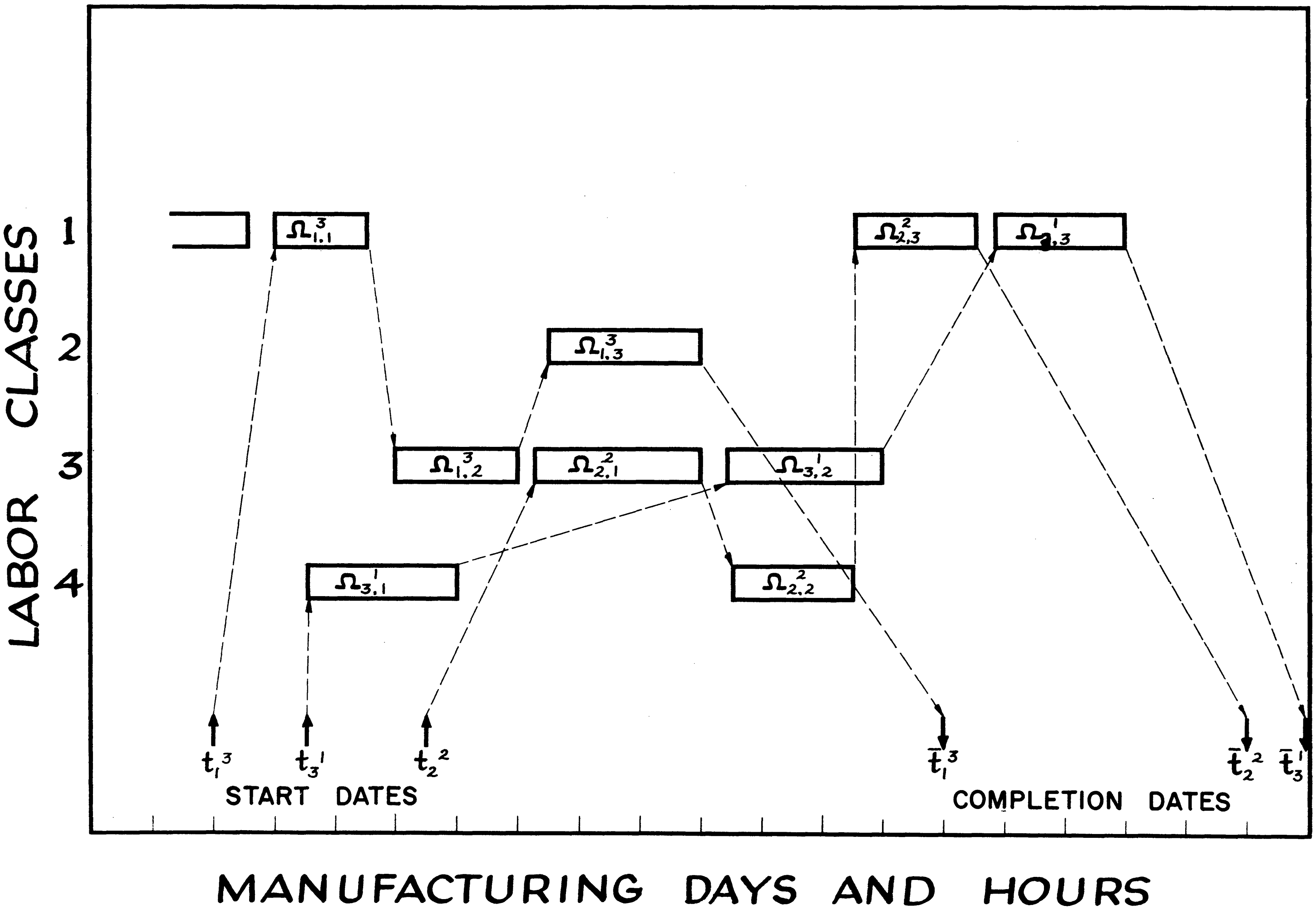

FIG. 2

Suppose we are looking at the plan this morning and trying to determine what operation we should perform. We observe that up to today we were on schedule and we have performed the three indicated operations according to our original chart shown in Figure 2. We recognize at this point that the second lot of A_2 has not arrived yet, and therefore operation $\Omega^2_{2,1}$ cannot be performed. Therefore, we perform (Figure 3) the second operation on the first lot of A_3, that is $\Omega^1_{3,2}$. We also perform operation $\Omega^3_{1,3}$ according to the old plan. After $\Omega^1_{3,2}$ is completed, the second lot of A_2 arrives and, consequently, the first operation $\Omega^2_{2,1}$ can be performed on machine 3. At this point, we recognize that our original chart is of no particular value, because things have changed so much that we have to develop a new chart. The event that a certain lot was not available is an "upset." The fact of the matter is that there are dozens of these "upsets" every day; machines break down, tools are not available, labor is not available, etc. This means, then, that quite often (possibly every day) a completely new chart would have to be developed. This is, in our particular case, an impossible job.

Furthermore, not only is it impractical to carry out the computations, but there is a conceptual difficulty. What is the point of carrying out this very elaborate scheduling computation, say for three months in advance, when we know that every day we will have to rework the whole schedule completely? Suppose every morning we could determine by some magic the "optimum" schedule. In what sense could such a plan be optimum if we have to change it tomorrow?

Earlier, we found it useful to look upon this problem in a different way.* Figure 4 shows the four production machines of our hypothetical problem. The available semifinished lots are conceived as forming a waiting line in front of each of the machines. $L^4_{3,2}$ refers to the fourth lot of A_3. The last index 2 denotes that the second operation was already performed. We placed this semifinished lot $L^4_{3,2}$ in front of machine 1. As shown in Figure 4, there are three lots waiting to get on the first machine, four lots to get on the second one, none for the third machine, and there are two lots waiting for the fourth machine. We assume that there is certain work being performed on each of the machines, with the possible exception of the third machine. Suppose now, that one of the lots that is being manufactured on one of the machines is completed. The foreman is faced with a decision problem: which of the semifinished lots waiting for his machine should he put on the machine?

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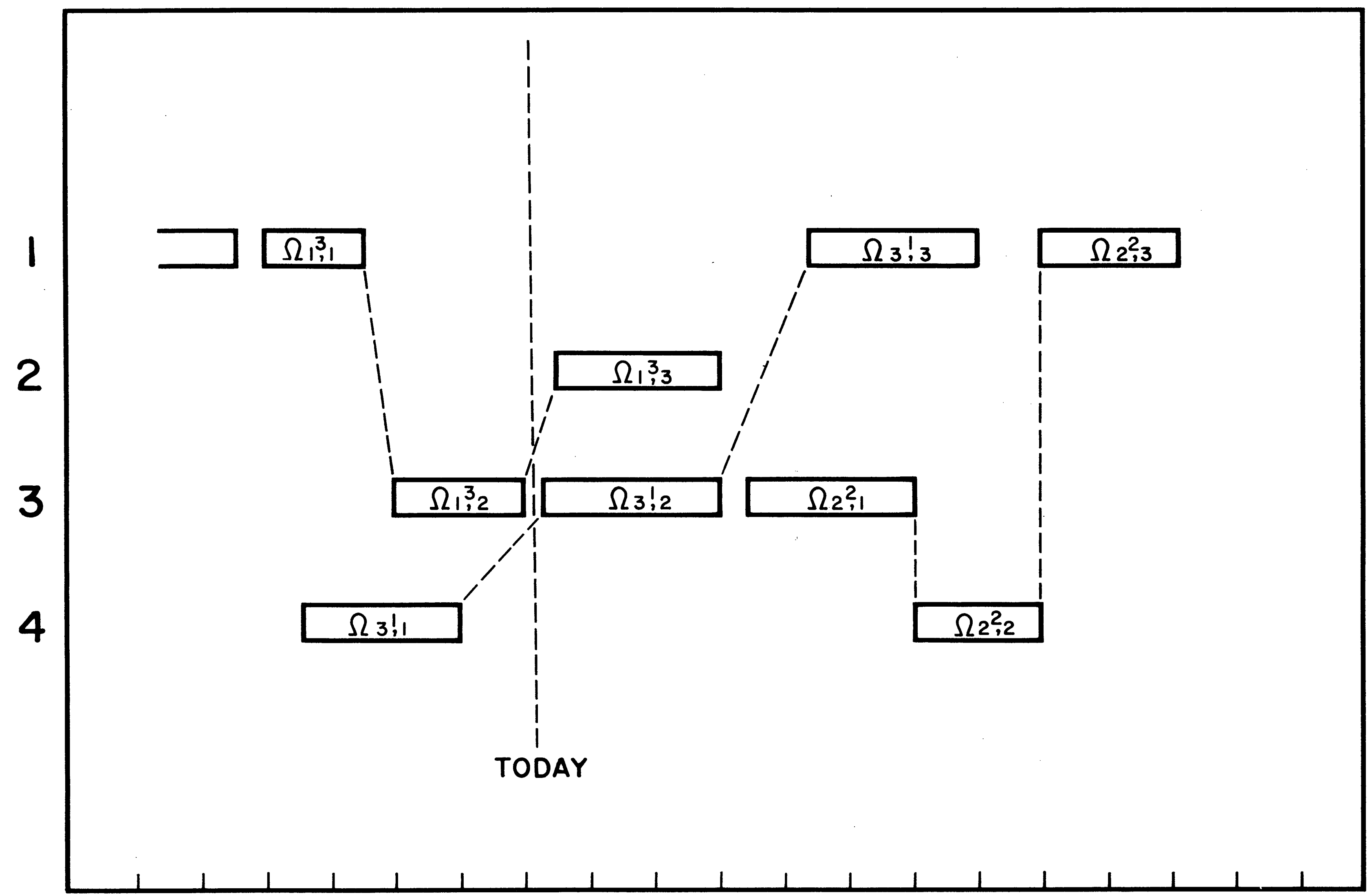
* A. Vazsonyi, "Production Control from the Point of View of Decision Theory," (Abstract), Management Science 1, pp. 190, (January 1955).

SHOP LOADING



MODIFICATION OF SHOP LOADING

FIG. 3

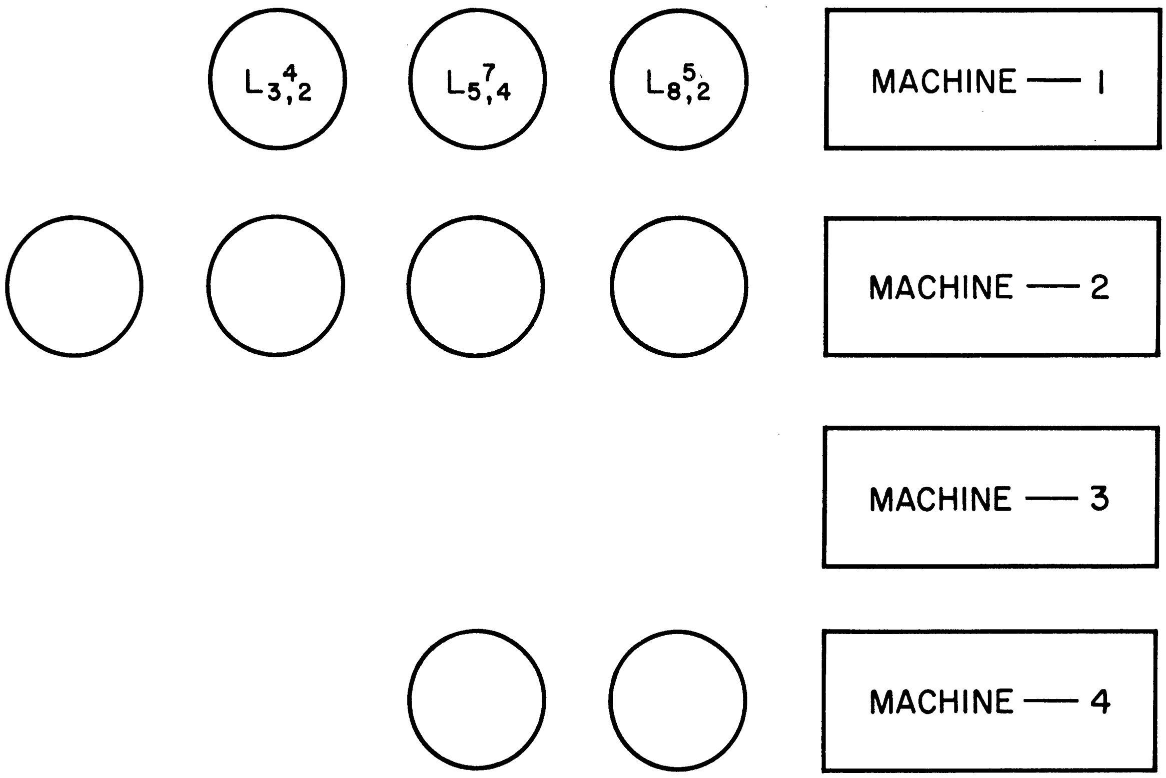


FIG.4 SHOP LOADING AS A PROBLEM IN WAITING LINES.

We formulate our problem in production control, then, as the problem of developing decision rules that will instruct or aid the foreman in what to do.

Let us speculate for a moment on the types of decision rules one could conceivably have. Suppose there is a master priority list of all the parts to be manufactured, and the foreman is instructed to take the lot that has the highest priority on the list. This would certainly be a possible decision rule.

The trouble with this decision rule is that parts that are low on priority list would be pushed back more and more, and perhaps never would be completed. Subassemblies would not be available and the manufacture of some assemblies would stop. As new orders came into the shop, some of these lots would be manufactured first, and production would get out of balance. Very likely the whole production system would collapse.

To speculate more, let us assume that the foreman would have an instrument, like a roulette wheel, to determine by chance what part should be manufactured. This situation might lead to somewhat better production than the previous method, because as time goes on every lot would be eventually manufactured. One would expect, however, that inventories would grow very large.

We can readily see what is wrong with either of these decision rules: the shipping schedule is not taken into account as far as the sequence of manufacturing is concerned. Presumably, raw materials and production orders would be released in "accordance" with the shipping schedule, but that is all that relates to the shipping schedule. What we need is a decision rule that somehow takes into account the shipping schedule.

Development of Decision Rules

In fact, the people in production control did have some decision rules of this type. They had some sort of a "feel" that told them just how long it takes to get certain parts through the shop. The difficulty, however, was that this "feel" was quite uncertain, and it varied from one person to another. In our terminology today, we would say that the decision rules were not explicitly formulated and stabilized. What was needed first was not so much the development of optimum scheduling procedures as a stabilization of the unwritten decision rules.

MANUFACTURING BANDS

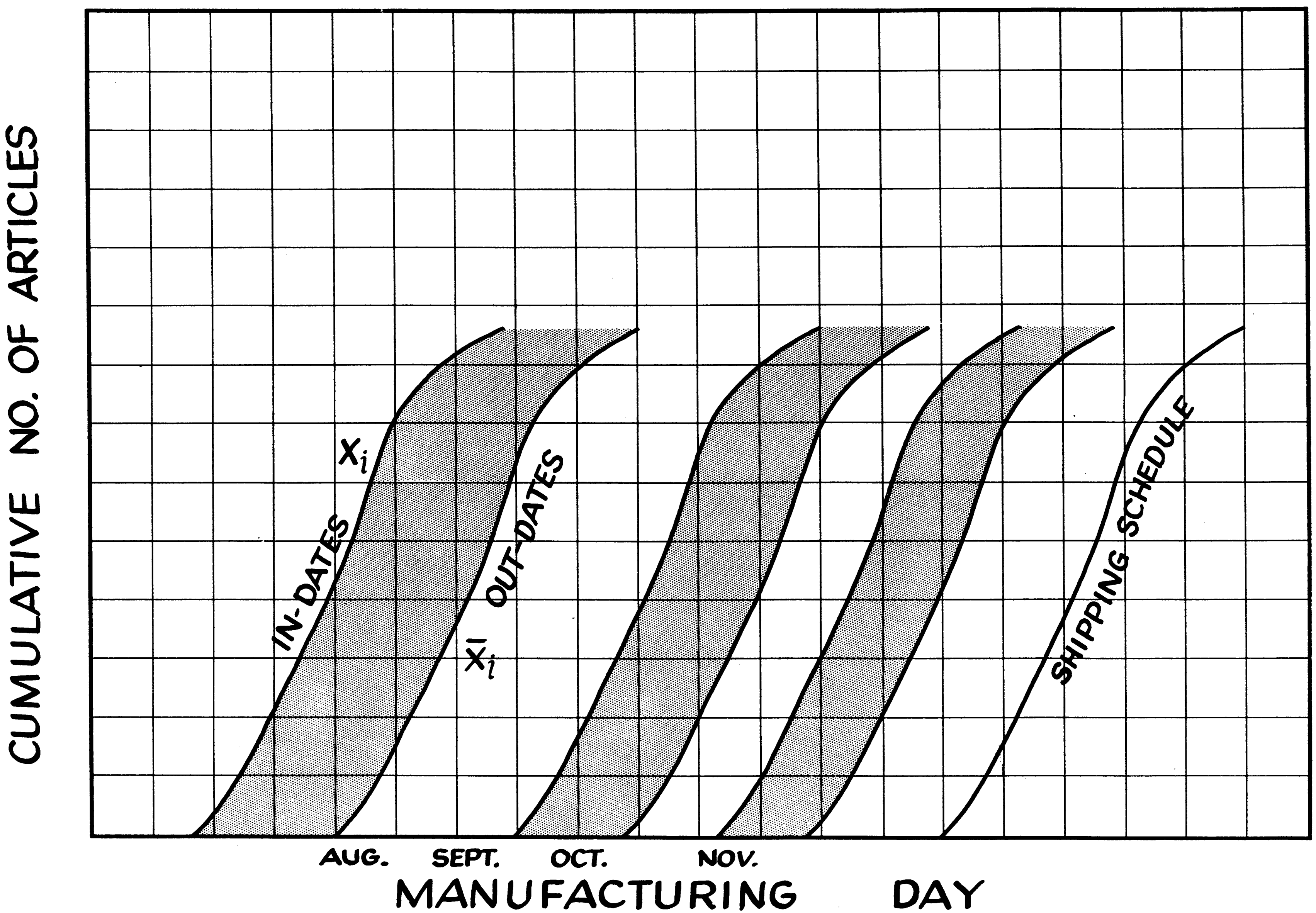


FIG. 5

MANUFACTURING BANDS

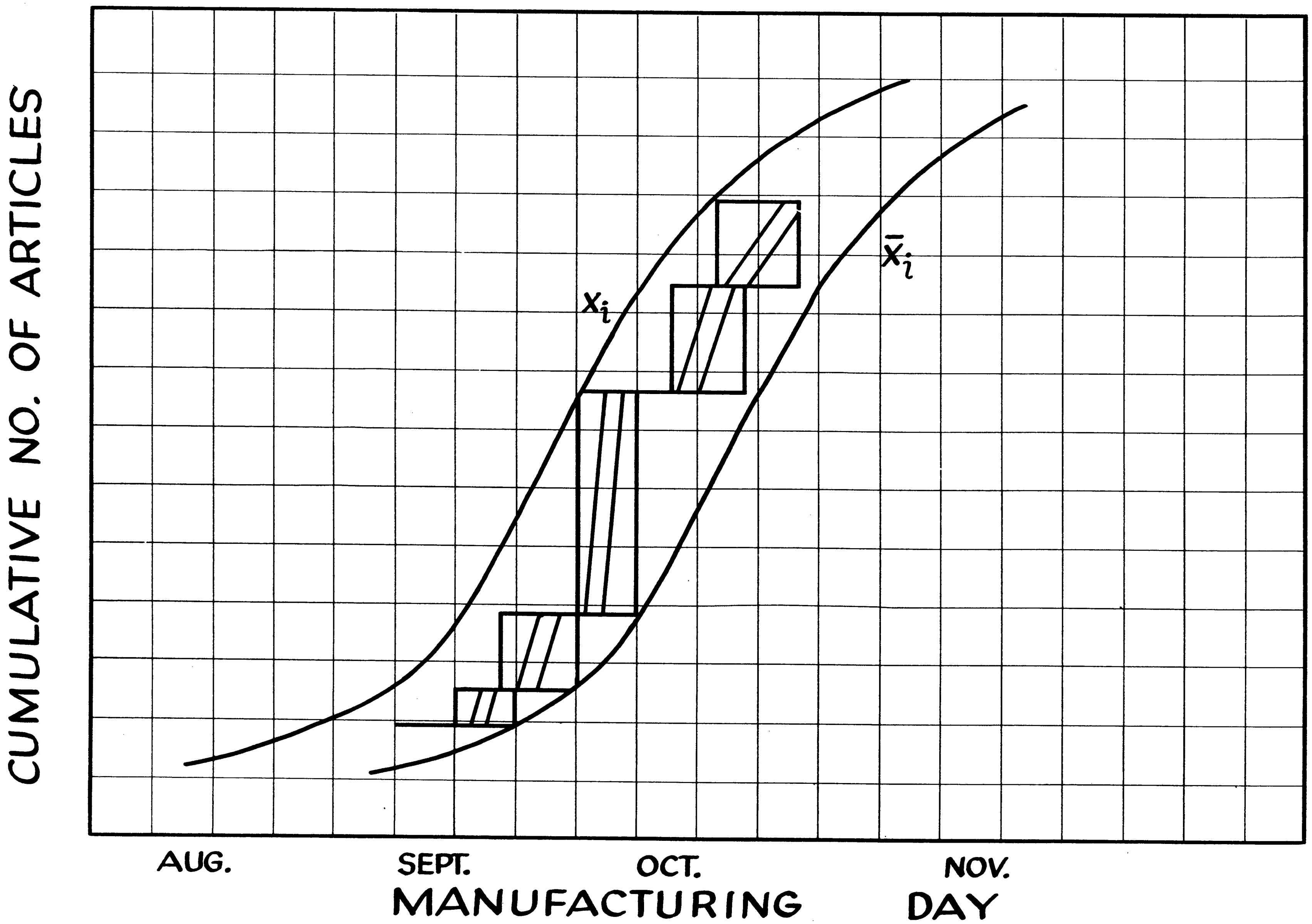


FIG. 6

The first step in the stabilization of the decision rules can be described with the aid of Figure 5. The horizontal scale is time, the vertical scale is the cumulative number of articles manufactured. On the right-hand side there is a line that denotes the shipping schedule, which tells how many articles should be shipped at what date. To the left of the shipping schedules shaded areas are shown, to be referred to as "manufacturing bands." Each of these bands refers to a particular article to be manufactured. The right-hand side edge of the band, labeled "outdate," refers to the cumulative number of articles that must be finished; the left-hand side, labeled "indate," refers to the cumulative number of articles that must be started. The actual manufacturing of the various lots of this particular article is conceived to be accomplished within the manufacturing band somehow, as shown in Figure 6. Indates and outdates for each lot can be computed, if the manufacturing bands are known. These indates and outdates will serve then as guides for the foreman to make decisions. Let us recognize, though, that the concept of manufacturing bands somehow implies that there is a fixed "flow time" for each article.

These ideas so far are somewhat vague, and many questions can be asked. How seriously should the foreman take these indates and outdates? How should the width of the manufacturing band be determined? Does this whole scheme make sense?

In order to answer these questions, let us make our proposition more precise. Let us assume that there is a fixed width for each manufacturing band, and that these widths, to be called "make-spans," can be represented by a setback chart as shown in Figure 7. Suppose we set up the hypothesis that the plant indeed has been operating according to a scheme of this sort. Is there any way to verify this hypothesis?

We could examine the records of the company and study the history of each individual lot. Then we could make a statistical study and determine whether there is statistical significance to substantiate our hypothesis. Remember, however, that there are thousands of types of parts involved, and that such a statistical study, therefore, would require a great deal of data. In our particular corporation, such data were not available and we, therefore, decided to set up a simpler hypothesis.

We made the hypothesis that the make-span of each article depends only on the number of operations involved and on the total standard time required to manufacture the particular lot. A multiple

SETBACK CHART

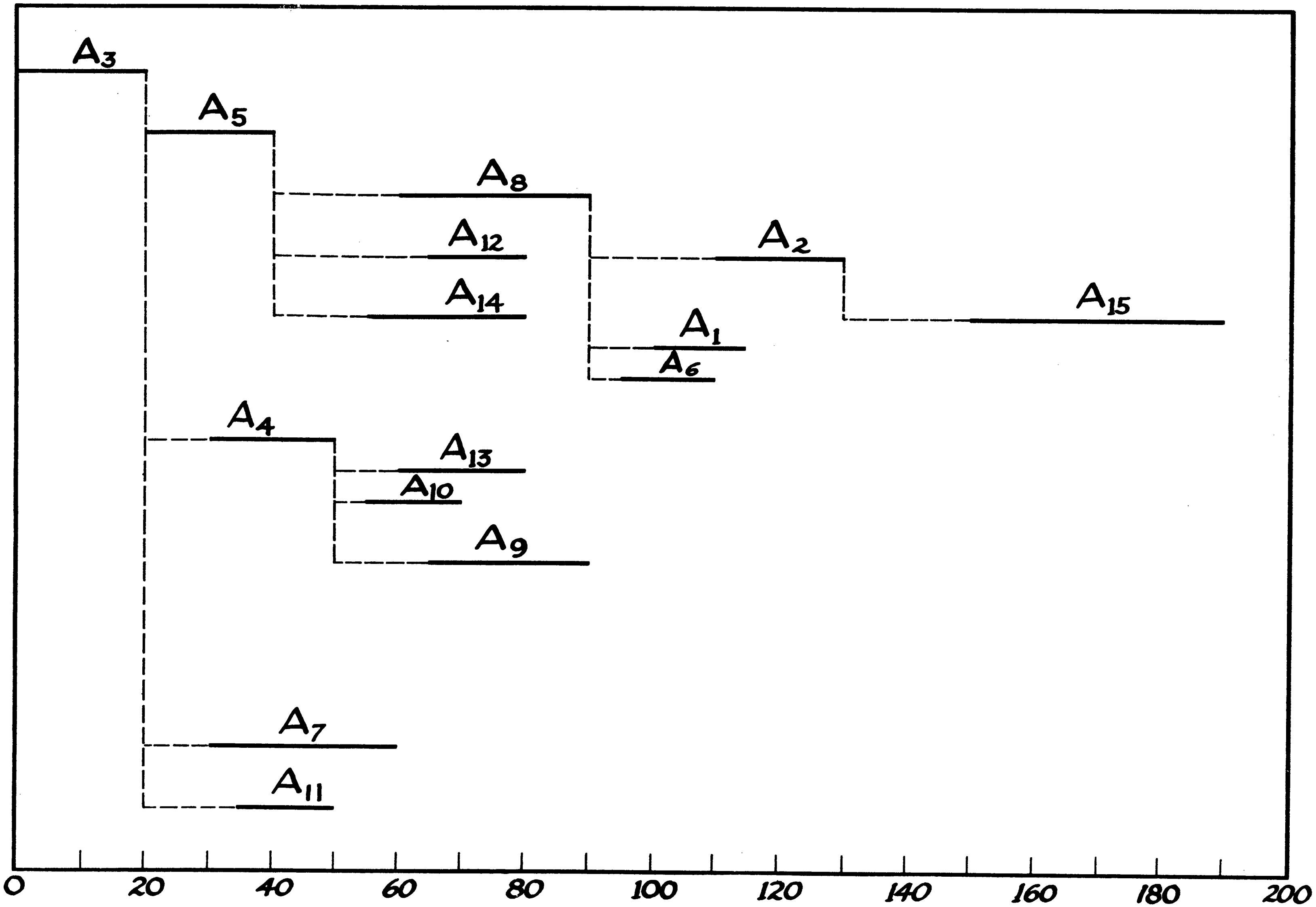


FIG. 7

regression analysis showed that the make-span in fact does not depend on the standard times, but correlates well with the number of operations. Figure 8 gives a hypothetical scatter diagram showing how the make-span is related to the number of operations.

On the basis of this correlation analysis, we have decided that it does make good sense to use these make-spans. We prepared a list of make-spans for each of the parts; we prepared set-back charts such as Figure 7, and we proceeded to install this production control system.

It will be of some interest here to describe some of the mathematical details of the scheduling procedure.

We denote by $\sigma_{i,k}$ the set-back of A_i in A_k. For instance, $\sigma_{8,3}$ is 90 days in Figure 7. We denote by s_i^m the number of articles A_i that must be shipped in the m'th production period. Finally, we denote by x_i^m the number of articles A_i that must be manufactured in the m'th production period to meet this shipping schedule. Then,

$$x_i^m = \sum_k T_{i,k} s_k^{m+\sigma_{i,k}} \tag{1}$$

where $T_{i,k}$ denotes the total number of articles A_i required for the shippable item A_k. (In the particular example we had here, this number would be 1 or 0, depending on whether the particular article is required in the shippable item or not.)*

In conjunction with our method of scheduling, we also developed a method of labor forecasting. One can readily see that once the make-span for every article is postulated there is a unique relation to predict labor loads. The total labor hours required in production period m on machine type n is given by

$$h_n^m = \sum_i \tau_{n,i} x_i^m, \tag{2}$$

where $\tau_{n,i}$ is the hours required to manufacture A_i on machine n, and h_n^m is the total hours required on machine n in period m.

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* A more detailed description is given by H. T. Larson and A. Vazsonyi, "Data Processor Requirements in Production and Inventory Control," Proceedings of the Western Joint Computer Conference, Los Angeles, (March 1955).

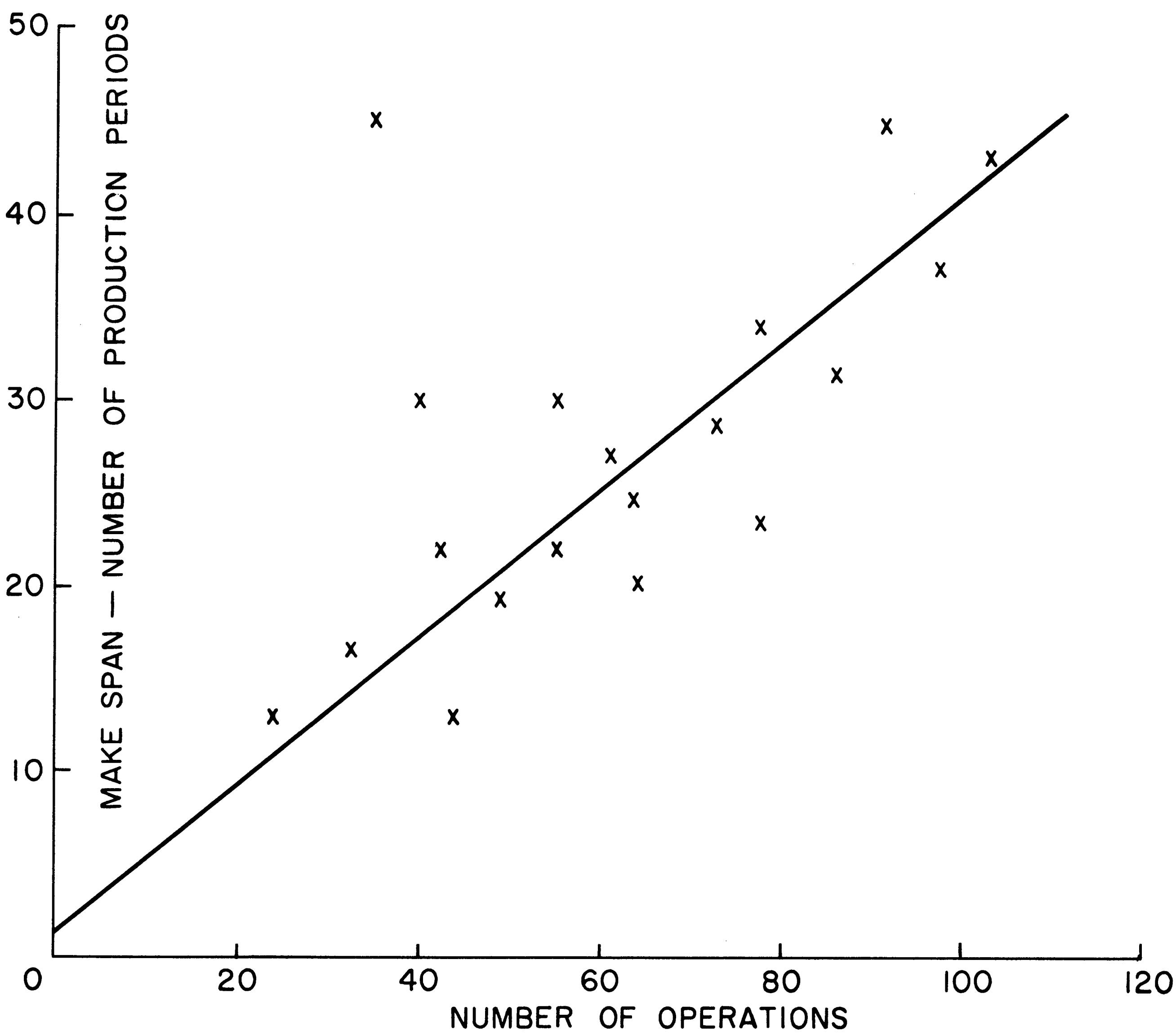

FIG. 8 STATISTICAL RELATIONSHIP BETWEEN NUMBER OF OPERATIONS AND MAKE SPAN.

The installation of this scheduling system required a great deal of systems and procedures work, the description of which lies beyond the purpose of this presentation. However, after the installation of this system it was recognized that in spite of the great improvements realized, and the large economic saving effected, there are still further improvements possible. This prompted us to continue our investigation and refine the scheduling system to a higher degree of precision.

Time Assignment Scheduling System

The scheduling system we have described so far, and which has been installed, specifies the start and completion dates for each lot of each part. This serves as an important guide but does not completely specify when each operation is to be performed. The system relies on a knowledge on the part of production personnel to fill in this gap and, in particular, utilizes decisions that must be based on judgment. In order to understand the problem better, let us consider now in detail how individual operations on each lot are to be performed.

In Figure 9, we show a detailed production plan for a particular lot. The two heavy dots represent start and completion dates. Each cross on the diagram represents a particular operation. For instance, it can be seen that the first operation takes two days. The second operation is performed on the third day, and the third operation is performed on the third day, too. The fourth operation takes three days, as shown in Figure 9 by the three crosses. The rest of the diagram shows the schedule of the rest of the operations. In the scheduling system previously described, only the two heavy dots were specified and the production personnel, so to speak, maneuvered between these two end points. Now, we wish to specify in detail when each operation is to be performed.

In order to carry out this detailed scheduling system, it was necessary to develop rules which specify what type of production lot is allowed one day, two days, or three days, etc., of manufacturing time. In order to develop these rules, it was necessary to know the standard times required to manufacture a lot, and the set-up time required to get the machine ready. The time required for a particular lot to be transported from one machine to another is of great importance here, too. We called this time the "transit time" and developed some general rules of what these transit times should be.

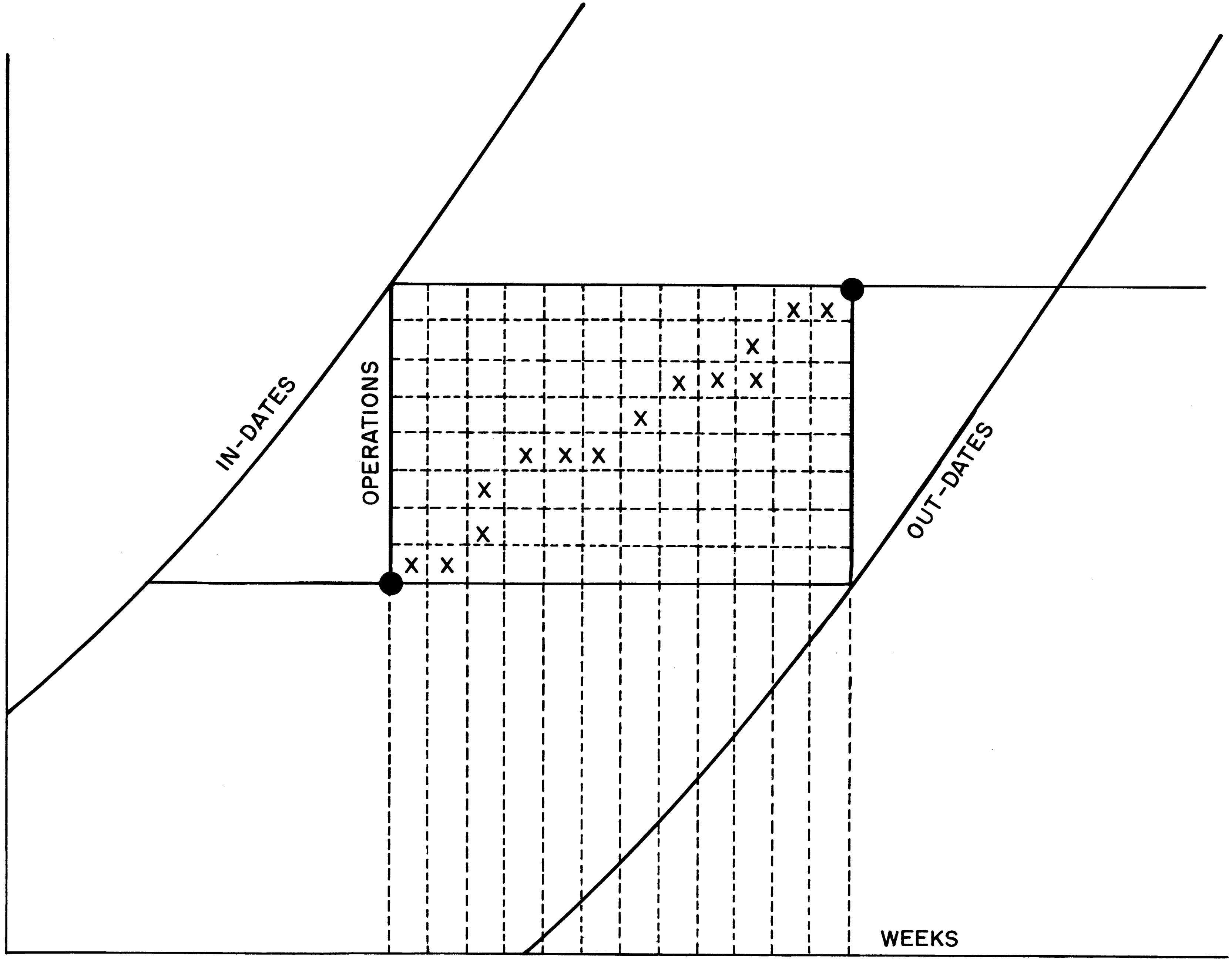

FIG. 9 TIME ASSIGNMENT SCHEDULING SYSTEM

Simulation of Scheduling

Consider a very simple production scheduling problem where four parts, P, Q, R, and S, are to be manufactured on machines α, β, γ, and δ. The production requirements are shown in Figure 10. It can be seen, for instance, that 100 of assembly P is required by the end of the sixth week, 80 by the end of the ninth week, 120 by the end of the twelfth week, and 85 by the end of the fifteenth week. Assembly P requires as parts Q, R, and S. As each assembly P requires two of Q, we have to have 200 Q's available when the first lot of assembly P is to be started. This means, as shown in the diagram, that 200 of part Q must be completed by the end of the third week. The schedule shown in Figure 10 can be interpreted in a similar fashion for the other parts.

The question arises whether this schedule is compatible with the machines available. In Figure 11, we show a schedule by two-hour intervals, which describes the production of all these assemblies and parts. The representation in Figure 11 is twofold. The lines headed by P^1, Q^1, R^1, S^1 show the history of the first lot of each part; the lines headed by α, β, γ, and δ show the history of each machine. (The two representations are somewhat redundant and must be in agreement.) We begin by producing the first lot of Q, i.e., Q^1. Figure 11 shows that Q^1 goes on machine β on day 1. Each symbol in Figure 11 denotes two hours of production, and so it can be seen that the first operation on lot Q^1 takes four hours. During the third quarter of day 1, Q^1 is in-transit to machine α. This is designated by the letter T. Then Q^1 goes on machine α for a six-hour period. As a comparison we see in the line headed α that Q^1 is, indeed, manufactured on machine α, as indicated by the letter Q^1. Then Q^1 is in-transit for two hours to go on machine γ where it stays for four hours. Then Q^1 is in-transit again, and becomes available as designated by the letter A. At the beginning of day 4, Q^1 is available for assembly. Manufacturing of P^1 on machine δ begins in the second quarter of day 4. This can be seen in the line headed by δ where the production of P^1 is listed. We also observe that according to the schedule we should have started P^1 on the fourth day, but we could not start it, since subassembly R^1 was in-transit. We list in the line headed by P^1 the letter D which shows that the start of P^1 is delayed.

The diagram in Figure 11 shows, then , a detailed description of the events that occur during the production of these parts. (The chart is to be continued for the subsequent lots of parts.) In order to prepare charts like Figure 11, it is necessary to consider all the important elements that enter into the production problem.

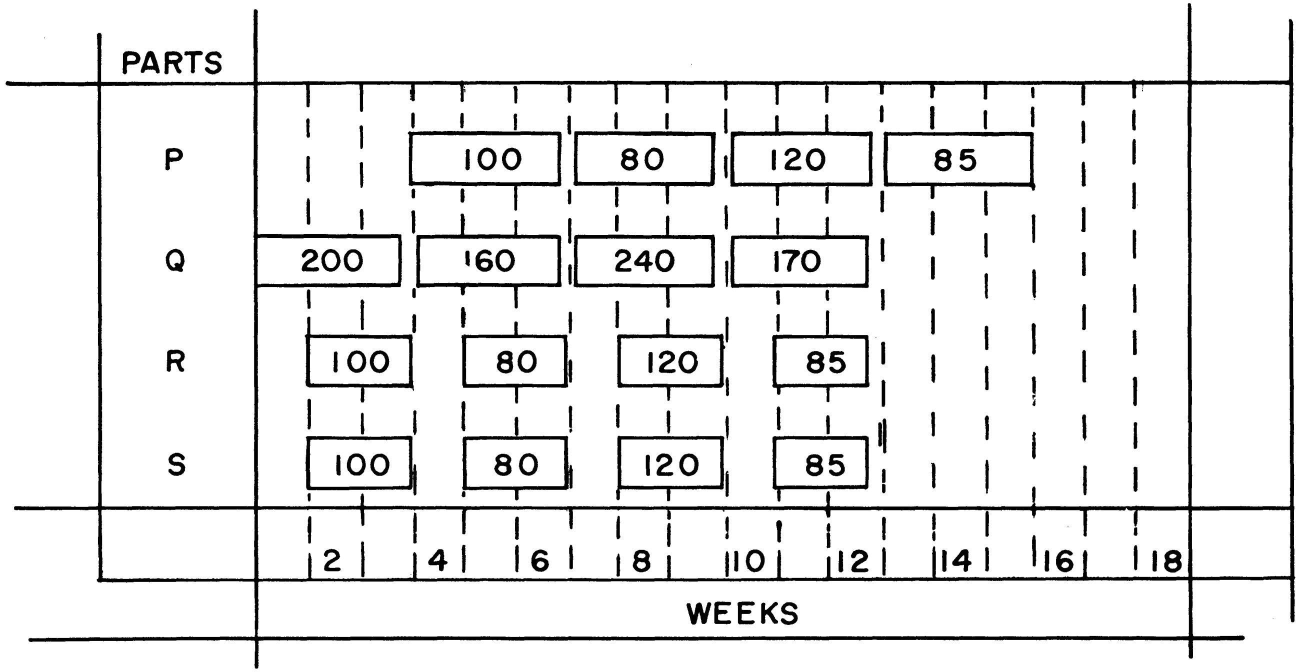

FIG. 10 GRAPHICAL REPRESENTATION OF SCHEDULES

		1	2	3	4	5	6	7	8	9
MACHINES	α	Q^1	Q^1 Q^1 R^1 S^1			R^2 R^2 Q^2 Q^2	Q^2 Q^2 S^2			
	β	Q^1 Q^1	Q^1	Q^1 S^1 S^1 R^1	Q^2 Q^2 Q^2		R^2 Q^2	S^2 S^2		
	γ		S^1 S^1	R^1		M M S^2 R^2	R^2			
	δ				P^1 P^1 P^1	P^1 P^1 P^1 P^1	P^1	P^2 P^2	P^2 P^2 P^2 P^2	P^2 P^2 P^2
ASSEMBLIES AND PARTS	Q^1	β β T α	α α T γ	γ T A A	A					
	R^1		W W α T	γ T W β	T					
	S^1		γ γ T α	T β β T	A					
	P^1				D δ δ δ	δ δ δ δ	δ T A A			
	Q^2				β β β T	T W α α	α α T β	T A A		
	R^2					α α T γ	γ T β T	A A A		
	S^2					W W γ T	W W α T	β β T		
	P^2							D D D δ	δ δ δ δ	δ δ δ

FIG. 11 REPRESENTATION OF SIMULATED PRODCTION PLAN

For instance, we note that machine γ on day 5, during the first and second quarter, is under maintenance as denoted by the letter M. There are many other factors that must be included in a realistic situation, but here for the sake of simplicity, these other factors are omitted.

In order to carry out, in a systematic fashion, the preparation of such schedules, it is necessary to have decision rules which specify what to do in each instant. In particular, when different parts compete for the same machine, there is a need for a decision rule to indicate which part should go on the machine first. More elaborate decision rules which relate more intimately the production schedule to the delivery requirements have been suggested by various authors.*

In addition to the specification of these decision rules, it is necessary to know the statistics of each of the factors that enter into production. The statistical distribution of the time it takes to manufacture a part is one of these factors. The statistical distribution of set-up time is necessary, too. We need to know the statistics of the time it takes for a part to be transported from one machine to another. Information on maintenance is required. However, when all this statistical information is available, and the decision rules are specified, then the scheduling process becomes automatic and can be performed with the aid of an electronic computer.

We illustrate, tentatively, in Figure 12 by a block diagram of how the simulation process could be performed. The basic input is the shipping schedule as shown on the left-hand side. The next block shows the set-back structure that is to be employed in the computations. Then we need to store in the memory of the computer the operations sheets which describe on what machines the particular part is to be manufactured, and in what sequence. We need to store information on maintenance statistics. The particular Time Assignment Scheduling System to be employed must be stored in the memory. We need to specify the particular decision rule to be employed, and finally we need to generate random numbers. This is the information from which the computer can prepare simulated production plans of the type shown in Figure 11. From each simulated production plan we obtain information about the effectiveness of the particular scheduling system employed. It is recognized here that no

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* A. Vazsonyi, "Operations Research in Production Control--A Progress Report," Operations Research, Volume 4, No. 1, February 1956, pp. 19-31. R. T. Nelson, "Priority Function Methods for Job-Lot Scheduling," Management Sciences Research Project, Discussion Paper No. 51, University of California, Los Angeles, February 24, 1955.

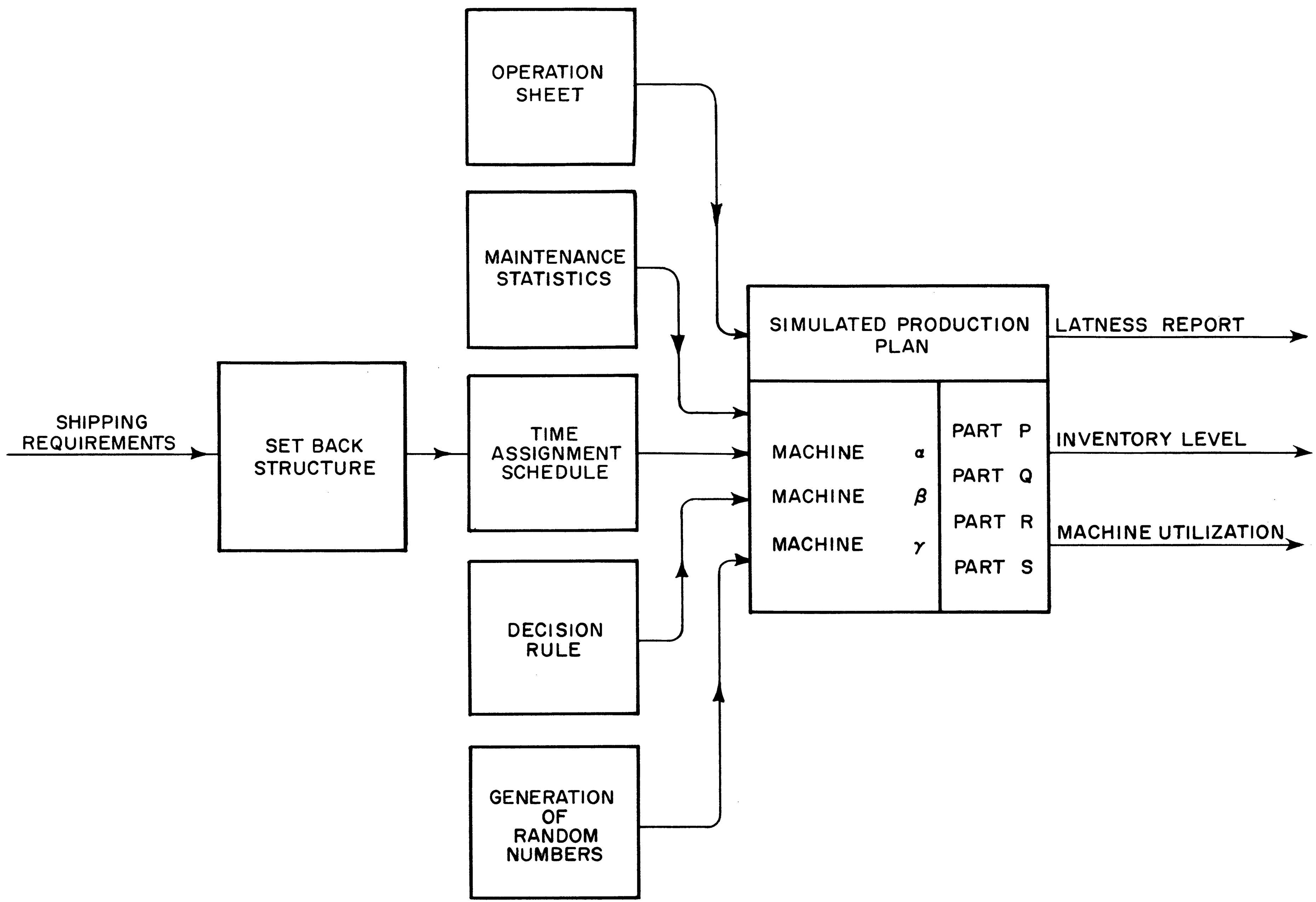

FIG. 12 BLOCK DIAGRAM OF SIMULATION

single measure of effectiveness is available yet to evaluate the performance of a schedule. In Figure 12 we show three important measures that may be used. One measure is lateness or earliness of delivery. Another one is the inventory level, and the third one is machine utilization.

Let us inject here that it may be too early to say what these measures of effectiveness should be; the important thing is to recognize that whatever measure is accepted, this measure can be computed once simulated production plans are developed.

In summary, then, the simulation process runs as follows. A particular set-back structure is predicated and then many Monte Carlo runs are made with different shipping requirements. With the aid of specified measures of effectiveness, the particular system of scheduling is evaluated. Then, proposed improvements in the scheduling system are introduced, new runs on the computer are made, and these proposed improvements are evaluated.

One of the important problems we plan to study is the problem of shortening lead-times. Instead of using the empirical set-back rules, (Figure 8), we plan to experiment with various proposals for shortening the lead-times. With the aid of simulation, we will evaluate the validity of these new set-back structures, and will determine whether these set-back structures are practical in actual production.

In summary, then, we can say that our point of view of looking at the problem of production control as a problem in decision theory has been fruitful. We have developed, installed, and tested certain decision rules in a rather complex situation. Our study started with the purpose of introducing high speed electronic data processors, but a great deal of work had to be done before it could be specified which electronic computer should be employed. This is not surprising, as one can readily see that the decision processes of production must be clearly developed before computers can effectively be applied. We have learned that by combining electronic computers with thorough system studies, very significant improvements can be realized. There is every reason to believe that continuation of this work will lead to further important benefits to Thompson Products, Inc.

"OPERATIONS RESEARCH IN INDUSTRY"

Symposium

May 7, 1957

PLANNING AND CONTROL OF SERVICE OPERATIONS

Leslie C. Edie
Chief, Project and Planning Division
The Port of New York Authority

"History sometimes happens quietly, without parades, without decisions and debates; even without anybody knowing at any determining instant that the change has come about. The clock may strike so softly that we do not hear it." Thus began an editorial in the New York Times a month ago. The event cited was the culmination of a long process. For the first time in this country, or in any country for that matter, the number of persons employed in the production of goods became fewer than those employed in the service occupations. This highly significant development may explain in part why we find quite a lot of Operations Research today being concerned with services - transportation, distribution, utilities, government, finances, etc.

The Port of New York Authority, the self-supporting corporate agency of the States of New Jersey and New York, belongs to this great family of service industries. It was created in 1921 by treaty between the two States to deal with the development and operation of terminal and transportation facilities, and to improve and protect the commerce of the Port District, an area within a 25-mile radius of the Statue of Liberty.

Port Authority Commissioners, six from each State, are appointed by the Governors of New Jersey and New York. They serve without pay for terms of six years, and perform functions similar to but even more extensive than those of a board of directors in a private corporation.

Under Port Authority operation, some nineteen facilities, representing an investment of almost $650,000,000, serve the transportation needs and the commerce of this great metropolitan region.

Much of the work at the Port of New York Authority is concerned with rendering service directly to the general public, or to businesses which in turn serve the public. Direct service is rendered at six tunnel and bridge facilities; first, by providing roadway capacity to motor vehicle patrons; and secondly, by supplying traffic control, security, emergency assistance and other necessities for the safe and efficient use of roadways. Service is rendered directly or indirectly at four major airports and one heliport by the provision of the facilities used by aircraft, and through sky cap service, car parking, ground transportation and many consumer services such as restaurants, stores, banks, etc. At four seaports, services include the provision of ship berths, and of cargo handling, storage and other harbor facilities. At four inland terminals, service include those necessary for the trucking and bus operations conducted therein. All of this is a lot of service and the planning for these many kinds of service operations and the control of those provided directly by the Port Authority obviously comprise a fertile field for the use of operations research.

In my talk this morning, I propose in the first place to discuss the approach taken at the Port Authority in applying Operations Research to these service operations. Then, to illustrate this approach by a specific example, I will describe in some detail a typical O.R. case history; namely, the planning and control of information service at the Port Authority Bus Terminal in midtown Manhattan. Finally, I shall mention a few other O.R. cases and describe the results achieved.

As for the approach, one often hears the question raised at conferences and symposia such as this about what problems should be tackled when one first undertakes the conscious application of O.R. to a business organization. This question no doubt has many answers depending on the particular business and its immediate circumstances. However, there are two approaches to the question which tend to stand out somewhat at opposite poles. One is to look for the most important problem of all in the entire business, namely that with the biggest payoff; the other is to look for the problem one can most likely handle and be satisfied with merely an adequate payoff.

Finding the most important problem of all, and solving it, would likely be the optimum approach if this can be done. This overall approach leads quite naturally it seems, to what is a "wholistic" attitude in the two senses of encompassing the entire business on the one hand; and of drawing on an unlimited multiplicity of scientific disciplines on the other. Much has been said from time to time on the need for this wholistic attitude toward the scope of the problem to avoid the evil of sub-optimization, and for the wholistic attitude toward the methodology to avoid limited and imprecise analysis, which might be called the evil of <u>under</u>-optimization. These deficiencies in delimiting one's attitude too severely certainly do exist, their hazards have been noted in the literature, and I would not minimize them.

There is nevertheless much to be said for the limited approach, at least, in the early development of O.R. in an organization. If one sets out to make a model of an entire business, or a large part of it, and attempts to optimize all segments simultaneously for maximum long-range profits and growth, it will be difficult to estimate how long the study will take, how large a team will be required, and how much it will cost. Nothing may be produced for a long while and it may be difficult within the period desired by top management to put the O.R. group on a financially self-sustaining basis, where demonstrated savings pay the costs of the continuing the grou
I have found this latter factor important to management's acceptance and continued support of O.R. Naturally you who are here from management do not

want to wait many years before you see tangible results from the operations research you pay for. There has not been so much in the literature about this particular hazard, which might be called the evil of over-optimization.

We have, at the Port Authority, been bothered considerably by the magnitude of the most important problems such as, for example, the optimum allocation of resources among the various transportation media. Because we have not felt capable of these larger things, the development of O.R. at the Port Authority since its beginning, five years ago, has been along the lines of limited studies with nominal budgets producing adequate payoffs. Thus far, O.R. personnel at the Port Authority have been fortunate in the problems selected. Our analysts have not as yet bitten off more than they could chew, even though some of the bites have been pretty tough and hard to swallow. All of the studies so far concluded have done far more than pay their way, and some in particular have yielded fairly spectacular results from quite small investments. It is thus that our analysts have nibbled away at this small problem and that, hoping eventually to be able to take bigger and bigger bites out of bigger and bigger problems.

With the heavy emphasis on service operations in the work of the Port Authority, it is to be expected that most of the small problems have encompassed stochastic processes. The solution of specific planning and controlling problems has involved the use of queuing theory, and the one selected for detail presentation today is a case in point. It is a straightforward problem of scheduling service, and I believe the methods and techniques employed are generally applicable to many other kinds of service problems.

The background of the problem is this: In 1951, the Port Authority opened a new type of bus terminal in midtown Manhattan. It was a new type because it provided for the handling of buses between New York City and suburban New Jersey points without running the buses on New York City streets. This was achieved by direct overhead ramp connections between the third floor, suburban level of the terminal and the Lincoln Tunnel. Figure 1 shows the terminal and the ramp connections.

Prior to the opening of this terminal, the prospective bus operator tenants requested the Port Authority to undertake the job of supplying information about bus schedules and rates to the public on a centralized basis. This would obviously be more efficient than separate information service furnished by each individual operator. A telephone information center was, therefore, established in the office of the Port Authority manager of the terminal, who was also made responsible for other public services such as baggage checking and porterage, lobby information service, and bus dispatching and announcing; and for operation and maintenance of the building.

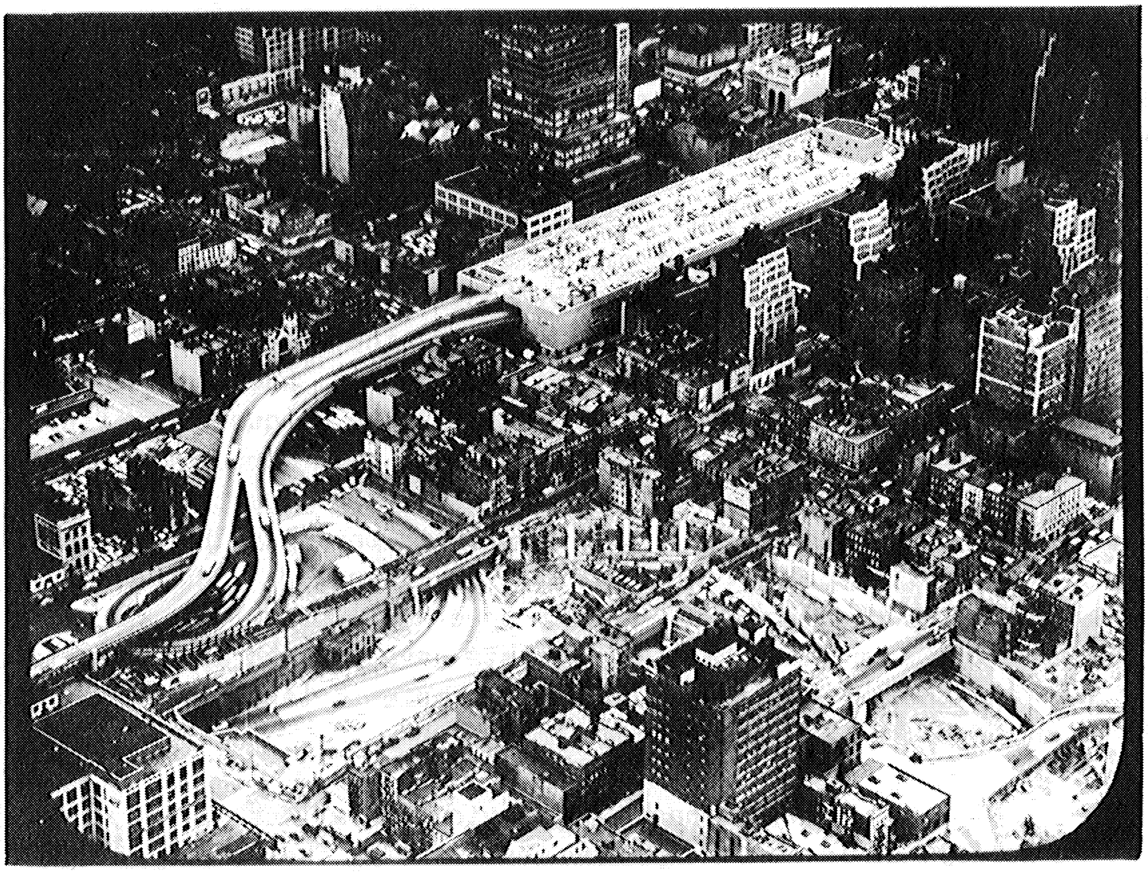

Figure 1

In the fall of 1954, after about three years of operation, the Director of the Terminals Department requested the Operations Standards Division, which has performed most of the operations research at the Port Authority, to analyze the information services from the standpoints of efficiency and quality of service. Approximately one million telephone calls were being answered annually by some thirty odd information agents. Direct operating expenses were running about $130,000 per year.

The analysis made of this operation comprises a classical type of O.R. and waiting problem, wherein two objectives are in conflict. While the overall study included the use of work simplification, methods engineering and other industrial engineering and industrial management practices, I will report on the questions relating to the queuing aspects of the study which I assume are of more interest to you.

It is in the queuing problem and related aspects of the telephone information service that the conflict of economy of operation on the one hand and service on the other come into focus. The maximum economy would be provided by having all information agents on duty work continuously with no idle time whatsoever; while the maximum service would be provided by having on duty at all times a number of agents equal to the maximum number of simultaneous calls which might occur. Consider a specific case of determining the number of agents required during an hour having 36 calls of 100 second duration each. If one wanted to handle them at bare minimum cost, he would assign only one agent, since the agent has a **capacity** just equal to the workload. However, if one wanted the best service possible, namely to be absolutely certain no call was delayed at all, he would require 36 agents. Between these two extremes of one agent on the one hand and 36 on the other is some compromise, representing the optimum service standard. It is management's job to determine just where and how this optimum compromise can be drawn in the first place and can be maintained in actual practice in the second.

There are essentially two ways of managing a service operation such as this. One way is by intuition, judgment, experience and rules of thumb. When this way is used, the grade of service rendered will probably vary appreciably from time to time. The number of agents available to provide service at any given time is first established by a budgeting procedure using a rule-of-thumb production standard. It is next determined by the judgment of the supervisor in the scheduling of reporting times and relief periods of the agents, based on his experience and intuition. Since supervisors may well be unduly affected by change circumstances, there is a tendency to shift assignments continually in an effort to meet these chance conditions. Overcompensations lead to excesses in agents at some times and deficiencies at others, even with the best of supervisors. This method of managing a service operation might be termed "flying without the seat of the pants." If we want to get down to the bare facts of the matter, we find many service operations are still run by this method, as you know; and so had been the telephone information service at the bus terminal for its first three years. A particular disadvantage of this method of planning and control is that the effect on service of increasing or decreasing the work force cannot be quantitatively evaluated before the fact, and after the fact such evaluation requires protracted observations to be accurate.

The other way of managing a service operation is to measure parameters carefully, forecast the traffic loads, and determine the relationship between the load, number of agents and the resulting service. Needless to say the O.R. team preferred this latter method of management. Incidentally, you may be interested in the composition of this team. It consisted of three analysts. The project leader was a senior engineer with masters degrees in mechanical and management engineering and with experience in communications and transportation. His two assistants also had degrees in management engineering and three to five years of such experience. You will note this is hardly the classical O.R. team; yet the work I am reporting on should qualify as operations research. When I say reporting, I mean just that since I was not a member of this team myself.

The first step taken by this team comprised a survey of other similar telephone centers. The survey was made for the obvious purpose of learning the best practices in effect in the field. This is, I think, a valid step in O.R. as in other work. The centers visited included other modes of transportation - railroads at the Grand Central Terminal, airplanes at the American Air Lines Reservation Center - as well as another bus telephone information center, namely that operated by Public Service Coordinated Transport in Newark, N. J. Visits were even made to department store telephone order centers. We also talked with the telephone company; however, methods applicable directly to our own problem were not found; so they had to be developed by solving our own forecasting, waiting and scheduling problem.

Traffic Analysis

A good place to start on such a problem is with a study of traffic behavior. This is looking at the input to the queuing operation. In order to set and maintain service standards, and to utilize personnel in an optimum manner, the workload must be amenable to measurement and prediction. Obviously, if the traffic does not behave in some generally rational and predictable fashion, one cannot in turn predict service results and cannot therefore schedule service ahead of time. The "seat of the pants" approach would be as good as any. In fact, it would be better than a prearranged operation rigidly adhered to despite the wild behavior of an irrational traffic volume.

The first characteristic of the telephone information traffic investigated in this study was the weekly variation in volume over a period of years. The purpose of this investigation was to uncover both seasonal changes and long-range trends. The results are shown in Figure 2, where weekly volumes are plotted against time.

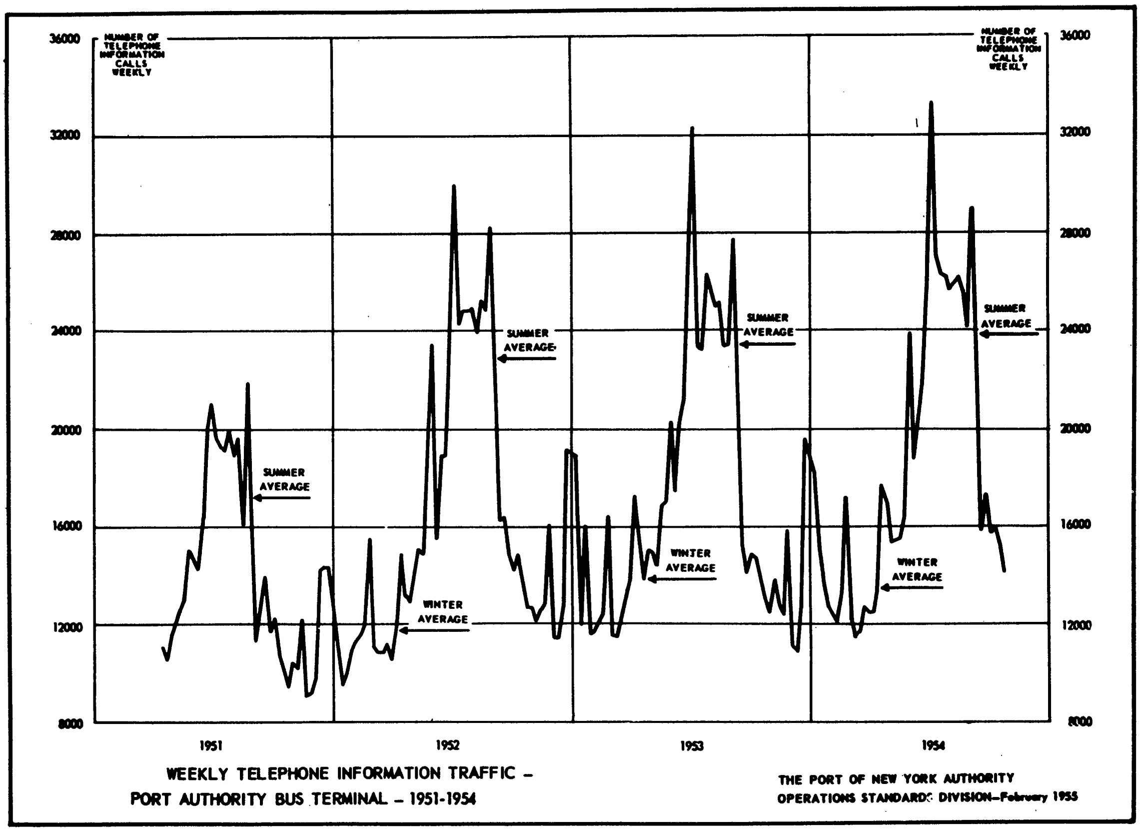

Figure 2

Observation of this chart suggests the following: (1) the seasonal fluctuations are reasonably consistent from year to year; (2) the summer upsurge begins in mid-May and ends in mid-September; and (3) there has been little change in average winter and average summer weekly volumes in the past three years. So far, so good.

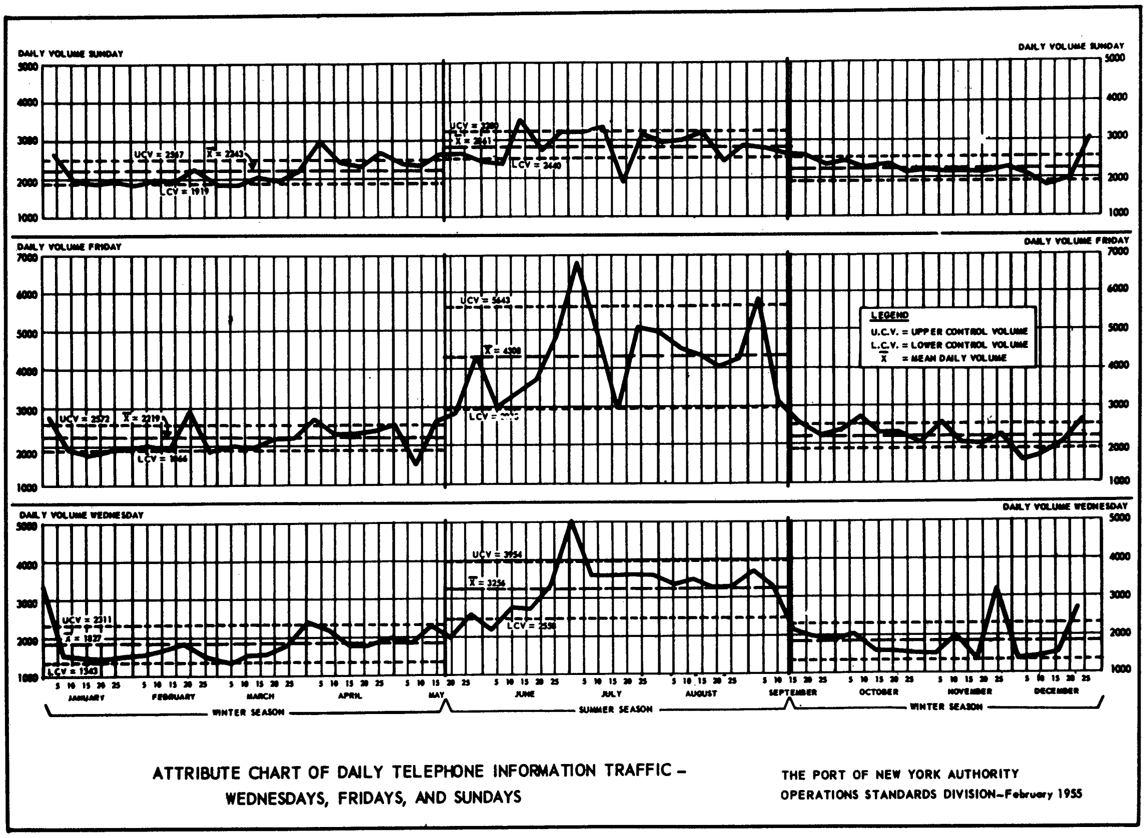

Figure 3

An analysis of the variations in daily traffic was also made on a seasonal basis, and to isolate individual days which were abnormally high, control limits were established in a manner similar to that used in statistical quality control. The limits were set at one standard deviation. Figure 3 shows how the daily traffic varied in comparison to the control limits for Wednesdays, Fridays and Sundays in 1953. The effects of certain holidays can be noted by the abnormal peaks. The Fourth of July, Labor Day, Thanksgiving, Christmas and New Years are notable. These could be separated from other days and would be given separate consideration. Another result of this analysis was that it revealed the similarity of certain days of the week. Using an analysis of variance, it was found that the first four days of the week in Winter as one case and first three in Summer for another case were alike in their behavior as far as total daily volumes were concerned.

The next step involved an investigation into the behavior of hourly volumes, i.e., how the daily volumes are distributed throughout the 24 hours. Here also those days having similar behavior with respect to total volume proved to have similar behavior in the hourly breakdown. Figure 4 shows how the hourly volumes varied for a typical day. The lowest curve is drawn through median points, the upper curve through peak points after eliminating abnormal holiday conditions, and the center curve is drawn midway between the outer two, and it gives a traffic measure with a safety factor.

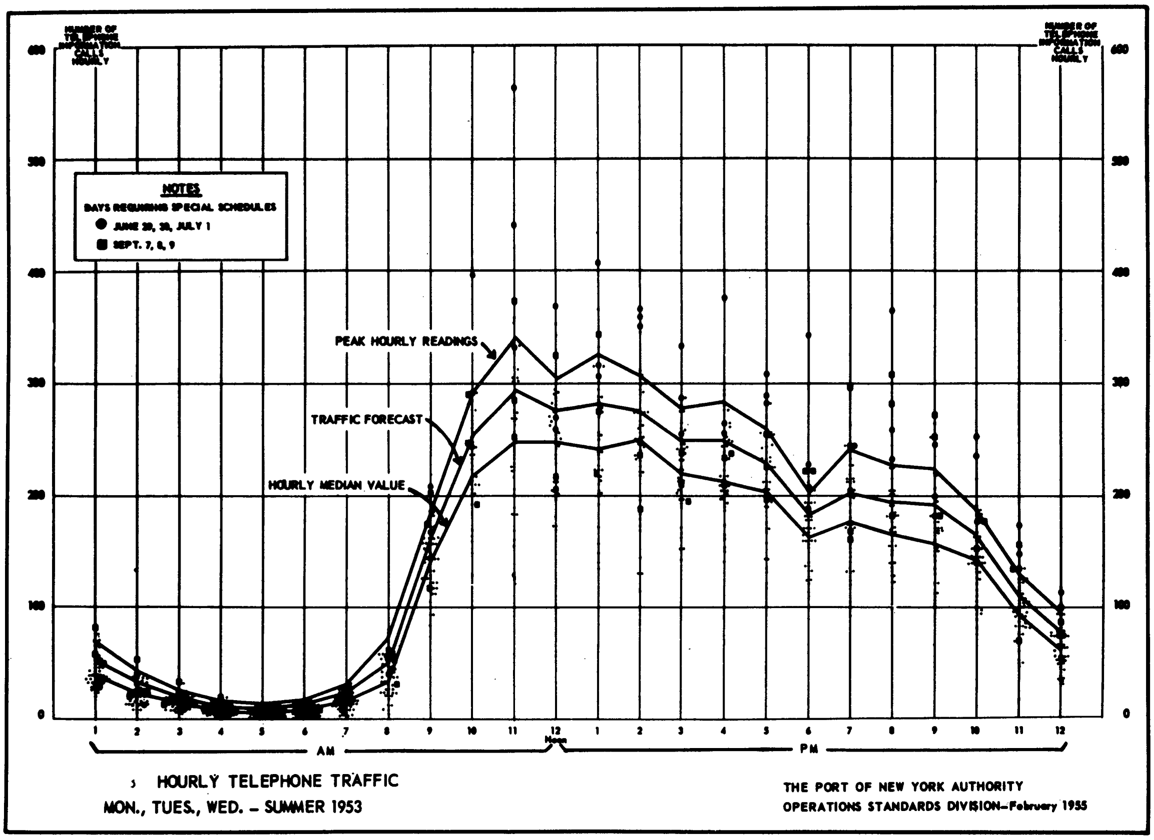

Figure 4

These analyses gave a good idea of how traffic volumes varied in the past. The next step was to develop ways of forecasting for the future; both long-range and short-range forecasts were desired. For long-range forecasts a relationship between bus movements and the number of telephone information requests suggested itself, as did the use of multiple correlation techniques. This proved fairly fruitful as Figure 5 shows, which compares the actual (the solid line) versus an estimate (broken line) based on estimated long-haul arrivals and departures and short-haul departures. The average error is less than 7%. The predictions for 1954 proved to be within 5%. For long range forecasts, weekly values are in sufficient detail for equipment and personnel planning, but for short-range forecasts, to cover the summer and winter requirements for 1955, daily and hourly forecasts were needed. These were obtained by assuming the same breakdown into days and hours as occurred in 1953. This could be done since no real trend had been found.

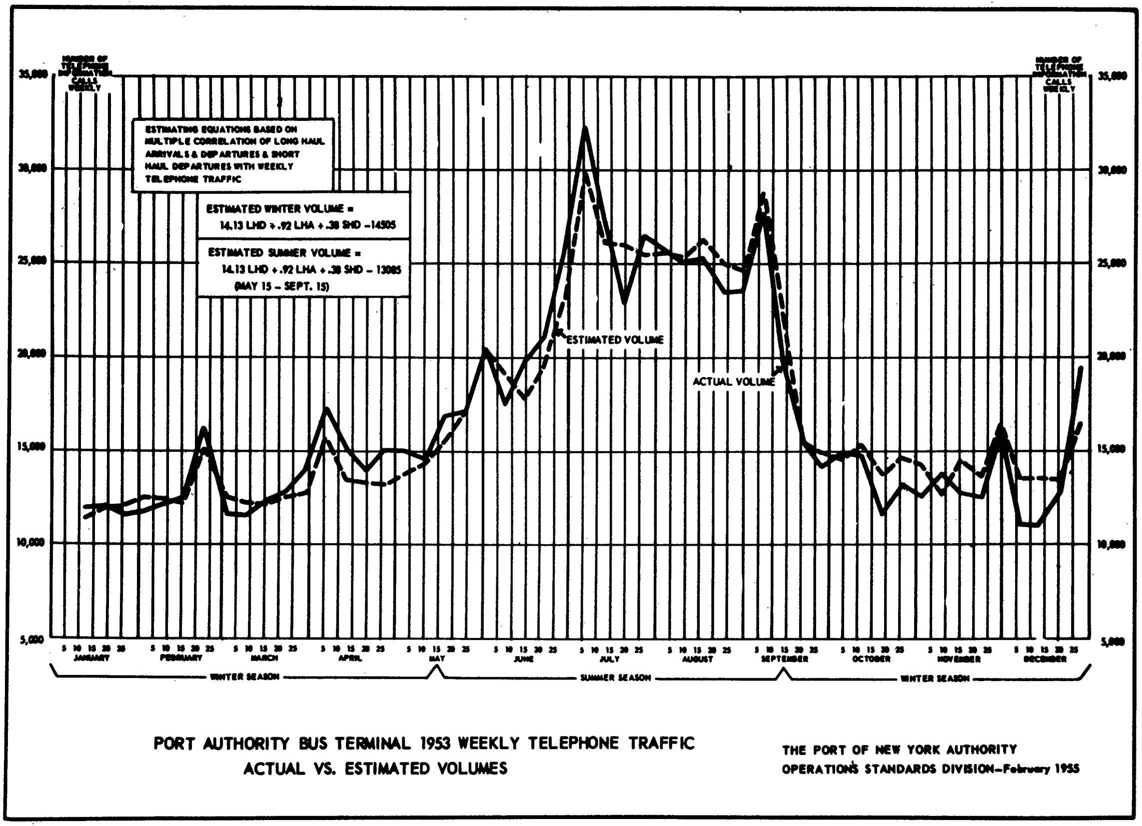

Figure 5

Analysis of Capacities

If traffic volumes are known, the maintenance of adequate and uniform service requires next the knowledge of how much traffic can be served by any number of agents for any desired grade of service. For example, if the traffic forecast is 200 calls in a certain hour and one wants to give an average answering service of 15 seconds (about 5 rings of the phone I think) then 6 agents might be required. If a better service standard of 10 seconds is desired, 7 agents might be required and for a low standard of 50 seconds only 5 might be required. To determine just what these relationships are one might investigate carefully the character of the traffic and of the servicing process.

Initial observations of the operation disclosed the following features:

1. Calls originate at random, which means simply that the call of any one subscriber is substantially independent in its timing of the call of any other subscriber.

2. Calls originating when all agents are busy are delayed and calls originating when all trunks are busy are lost. (There are 22 trunks for 14 positions).

3. Delayed calls are served in random order; i.e. any waiting call in a group of waiting calls has the same chance of being answered next as any other call.

4. Full availability exists; i.e., any free agent could answer any incoming or waiting call.

5. Statistical equilibrium exists; i.e., the average arrival rate of calls remain essentially constant during a period of time of one hour.

These characteristics can be observed or inferred rather easily in most kinds of delay problems that I have investigated. It is, of course, best however, to make measurements and counts to verify such inferences. Having done so, one can then search the literature on queuing theory to see if there is an available theory which will fit precisely the observed characteristics.

Fortunately, in this case, there was a theory published by John Riordan, in the Bell System Technical Journal, January 1953 which appeared to fit the characteristics of the telephone information service pretty well. This was a theory for delayed traffic served in a random order, and the aforementioned characteristics met all the assumptions of the theory but one. This additional one required that the durations of information calls also be random, i.e. be distributed according to what is called the exponential distribution. This distribution arises when a call in progress has just as much likelihood of terminating at any one time as at any other. In other words, the time when a call will end cannot be any better predicted if one knows when it started than if one doesn't know. This most peculiar phenomenon occurs in a surprising number of processes, all the way from atomic fission to traffic on a highway and the absences of employees due to an aggregate of miscellaneous illnesses. We find that whenever the grouping of events in time is randomly distributed, the intervals between the events are exponentially distributed.

Well, how does one determine that call durations or holding times are exponentially distributed? One answer is to measure them and compare the results with an exponential distribution. This was done in our case by monitoring calls, timing them with a stop watch. The observations were made separately in summer and winter months and at various times of day and traffic volumes.

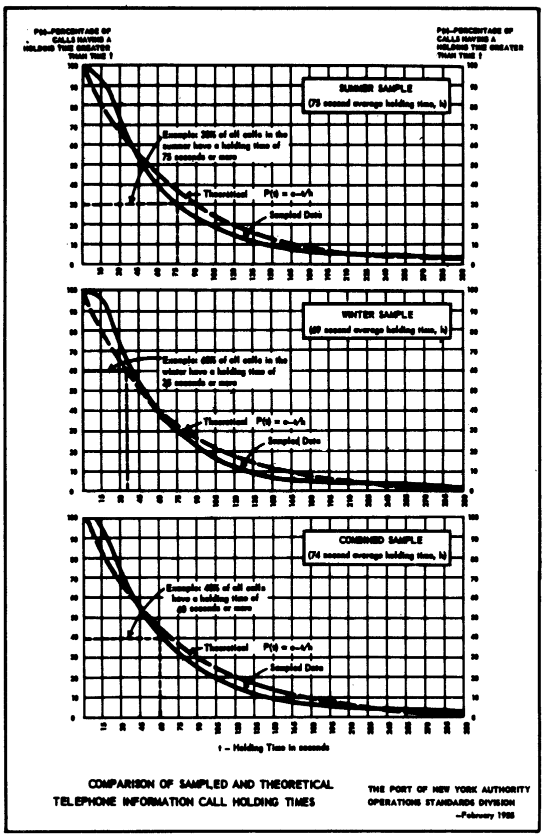

Figure 6

Figure 6 shows the results of comparing actual call durations with those predicted by the exponential law. The top chart shows results for the summer observations when the average call duration was found to be 75 seconds. The solid-line curve gives the observed distribution and the dotted line gives the theoretical. The units of measure on the vertical axis are percentages and those on the horizontal axis are seconds. A point on either curve gives the percentage of all calls having durations at least as long as the time value of the point. The example illustrated shows that 30% of all calls in the summer have durations exceeding 75 seconds. The center chart illustrates the results for winter traffic when the average call duration was found to be 69 seconds. The lower chart gives the combined summer and winter samples with an average of 74 seconds. (There were more summer observations than winter).

The fit of observed results to theoretical results appears to be close enough to justify an assumption that the exponential law holds just by observing the fits of the two curves. A precise quantitative measure (which is usually sought in operations research) is given by how often the misfit found could arise as a sampling error. In the examples, the degree of misfit could arise by chance in 43% of samples of the size taken in the summer, and in 60% of samples of the size taken in the winter. These results and the other characteristics of the traffic justify the use of queuing theory based on random calls, random service and exponentially distributed servicing times. This was fortunate in greatly simplifying the problem as compared to toll booth operations, for instance, where classical theories would not fit. Incidentally, the fact that local telephone calls generally behave in this exponential fashion has been cited by someone, whose name I have forgotten, as evidence of the fanciful behavior of human beings. Given fairly comfortable temperature and humidity, and a fairly comfortable seat there is no telling how long a telephone conversation may last.

Constancy of Average Call Duration

In applying queuing theory, the process is generally one of determining the capacity of a system to handle traffic at different delay levels. The capacity of traffic measured in numbers of calls only will obviously not be suitable if the average duration varies at different times. It is desirable, therefore, to investigate the constancy of average duration from two standpoints: first, whether it varies hourly, daily, or seasonally; and secondly whether it varies for different degrees of system saturation. The sample taken for the exponential distribution was also useful for this particular determination. A common phenomenon in delay situations involving human beings is for persons concerned in the process to speed up as congestion develops. This was found to be true for toll booths, where average transaction time would drop from 12 seconds with light saturation to 8 seconds with heavy saturation. However, for the telephone information service this was not the case. The inquirer could not know when other calls were waiting and apparently the telephone information agent could do little to expedite the call even though she tried. Thus, wide variations in mean servicing time was not a problem, even though individual calls did vary by extremes.

Applying Theory

Now we are ready to use the theory selected. Once one has definitely established that a well developed queuing theory will fit the operation he is dealing with, and he has measured his own parameter, such as servicing time and traffic rates, the actual application of the theory has in some cases been made easy by helpful persons who have computed and plotted working curves from which values may be read directly. Such was the case in this instance. Figure shows the form in which one sometimes finds queuing theory presented so that extensive calculations with complicated formulae are unnecessary. This figure shows average delay (t) measured in multiples of average servicing or holding time (h). The units ($\bar{t}/h$) are laid out along the vertical axis on a logarithmic scale. Along the horizontal axis, also in logarithmic scale, are the number of paths or channels (c) - in our case information agents. The family of

AVERAGE DELAY, EXPONENTIAL HOLDING TIMES. RANDOM ORDER OR QUEUED ORDER.

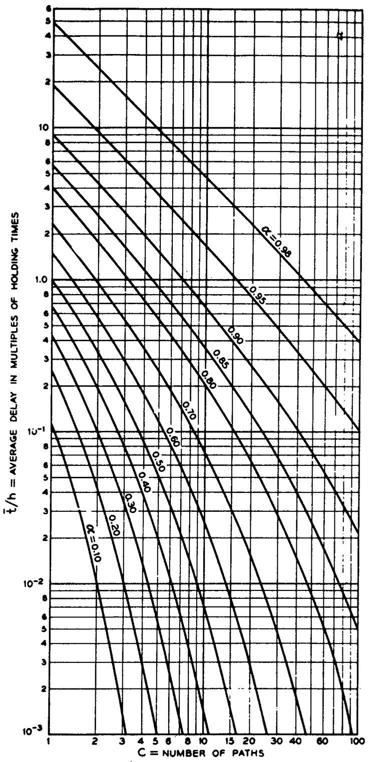

Figure 7

curves drawn on these coordinates are for various degrees of system saturation measured as a ratio of workload handled to full-time capacity. For example, if an agent handles in one hour 18 calls of an average duration of 100 seconds each, his workload is 1800 call seconds. Since his full-time capacity in an hour is 3600 call seconds, his saturation is 50%. Now suppose one wishes to estimate the ability of 6 agents to handle calls of 75-seconds average duration and give a grade of service of 15 seconds average answering delay. The ratio of delay to duration is 15/75 = 0.2. Thus one can find where the ordinate $(\bar{t}/h) = 0.2$ intersects the abscissa for c = 6 agents and then estimate the permissible saturation. It is 71%. The workload for each agent then is 71% of 3600 seconds or 2550 call seconds. If calls average 75 seconds, each agent can handle 34 average calls, and all 6 together can handle 204. All other values of average delay for 6 agents and other groups of agents can be determined similarly to produce curves reading directly in terms of agent capacity, number of agents and delays. Figure 8 shows the results. The specific example illustrated therein is the one previously computed.

Maximum Delays

A similar process can be followed to determine maximum delay relationships starting with curves that show the probabilities of getting delays of various amounts for different traffic saturations. Maximums need

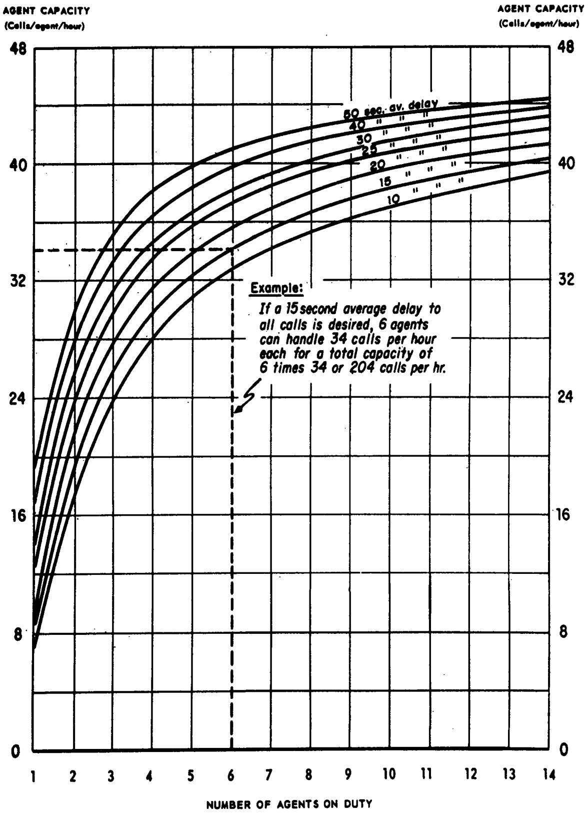

Figure 8

to be investigated since it is little consolation to one whose call has been delayed many minutes, causing him to miss a bus, for him to be told if he will call frequently, he will find his average delay to be quite nominal Averages in queuing problems are like those of a certain pullman porter. In this story a traveler is leaving a train after a night in the pullman. Not having ridden on a train for some time, he was uncertain about the size of tip to give the porter. Being a frank fellow, he decided just to ask the porter, who was standing in his usual position, so he said "What size tip do you usually get these days?" "Ah averages about two dollars, Suh" answered the porter without hesitation. "My", exclaimed the traveler with surprise, "Isn't that rather high?" "Might seem high to you suh", said the porter, "But yo see suh, I seldom gits the average". Such is our experience with queuing problems.

In estimating maximum delays one must decide what probability level to use. It is common to use levels of 0.1%, 1% or 5%, and the choice is often somewhat arbitrarily made. The same was true in this case where the 5% level was chosen, which gives a value of delay within which 95% of the calls are answered. There were two reasons for this choice. First, this probability level is used by some telephone companies to set answering standards, and seco it resulted in a reasonable relationship with average delay values and how the

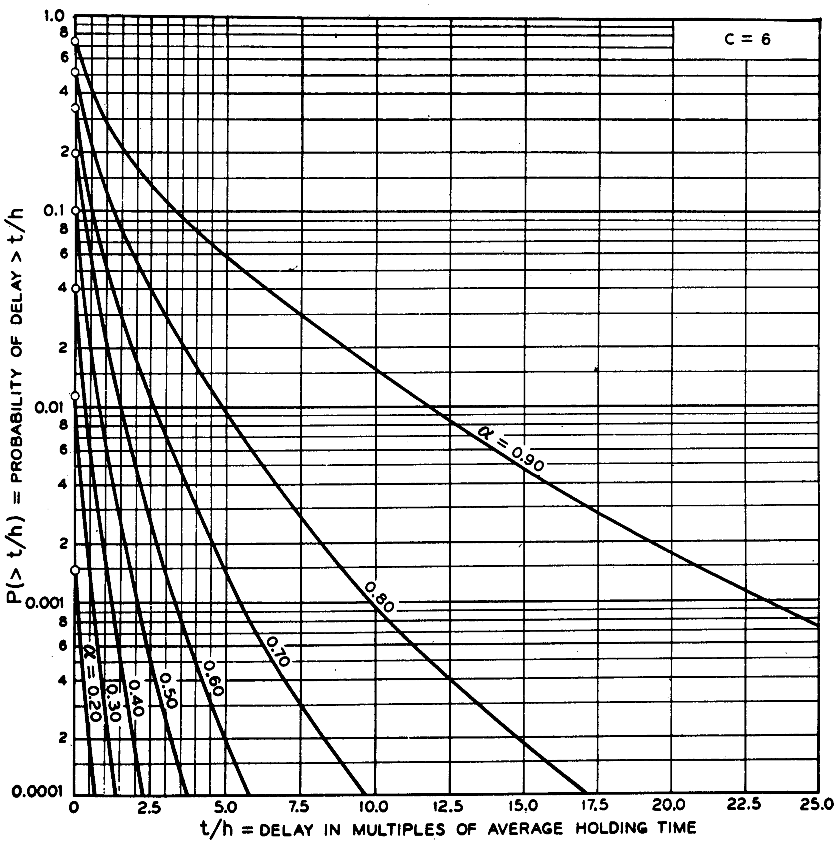

Figure 9

varied for different saturations. Figure 9 shows delay distributions for a group of c=6 agents for various system saturations. The horizontal axis gives delays in multiples of holding time and the vertical axis gives probabilities. Take the case of determining allowable saturation for a maximum delay of one holding time at the 5% level; i.e., what saturation can be used so that 95% of the calls are answered in less than say 75 seconds. The answer is 70%, so that 6 agents can handle 204 calls per hour and meet this standard.

Figure 10 shows this and other agent capacities found at the 5% probability level. The example illustrated is the same as previously used of 6 agents handling 204 calls.

Setting Standards

Having solved the waiting problem in terms of average and maximum delays one must next set service standards before determining manpower requirements. As you may already have suspected the standards chosen were 15 seconds average delay and 75 seconds maximum delay. The standards, as in the case of the probability level, were somewhat arbitrarily chosen. The average delay

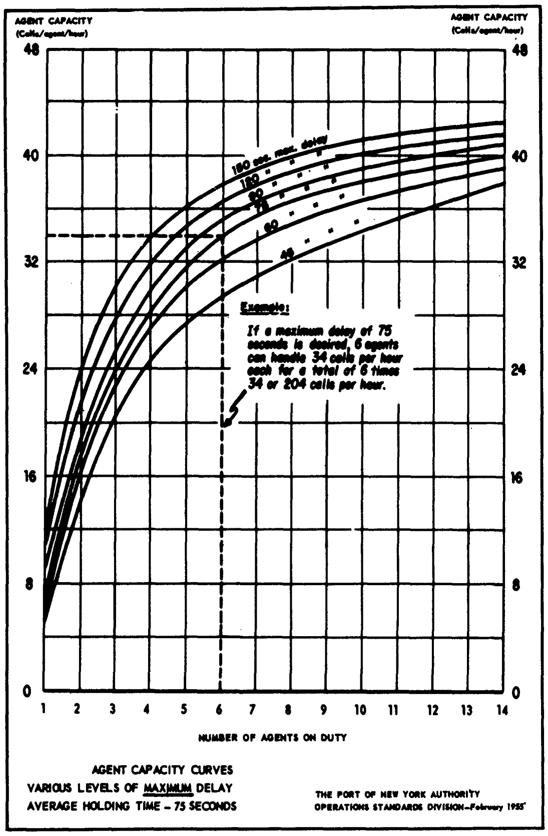

Figure 10

standard was selected according to what general level was being provided in similar service conscious centers. This standard is a liberal one from an overall standpoint, since generally it means that 3600 seconds of information agent time would be added to the manning whenever this would save the inquiring public only about 1,000 seconds of their aggregated time. The balancing of telephone agent time against the waiting time of callers would have yielded average delays measured in minutes rather than 15 seconds. Some information and reservation centers seem to operate according to some such standard, but in spite of its seeming logic it is hardly satisfactory.

Instead of this in our case, the number of agents working at each time of the day was determined by whichever standard called for the greater number of agents. Figure 11 shows agent capacities meeting both average and maximum delays standards for several different mean holding time values. This about illustrates the increased production resulting from reduced holding time If by training and improved practices, the average holding time can be reduced by only 10 seconds, from 75 to 65, capacity would increase from 34 calls per hour to 41 calls per hour - over 20%.

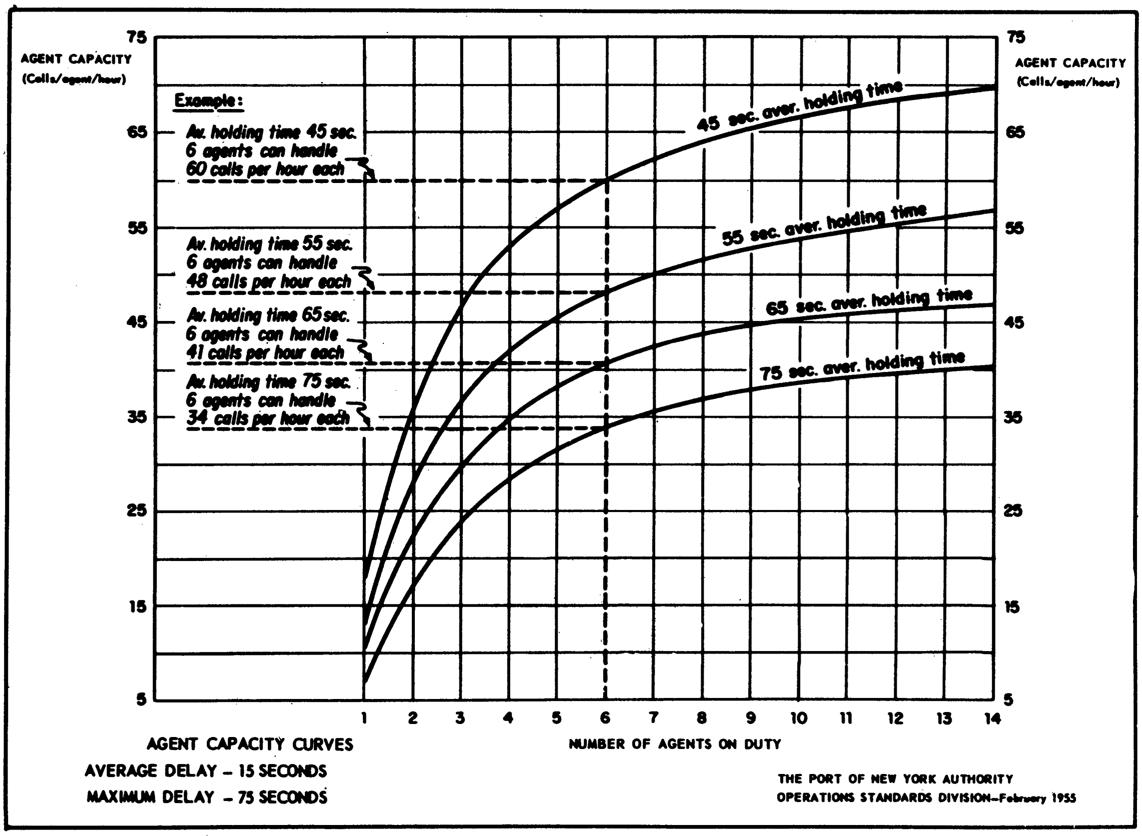

Figure 11

Scheduling

Up to this point, the study had produced tools by which the manpower requirements at the information center could be evaluated according to the rates at which agents could handle incoming traffic within established standards of service. The problem was still not solved, however, since a thorough knowledge of the foregoing aspects still did not provide a scheduler with a means of determining how to assure exactly the right number of agents on duty at all hours of the day, all days of the year. Our next step, therefore, was to develop a set of schedules which would fit all conditions encountered throughout a year. This was done by means of Gantt type charts, an example of which is shown in Figure 12, the next slide. This chart shows the assignments of 18 agents for the 8A - 4P, and 4P - 12M tours on Mondays through Wednesdays to meet service and relief requirements during the summer.

The process was not quite as simple as it might first appear. You will note that at the top of the chart, the day is divided in 15 minute intervals, and in each 15 minute interval is indicated the number of agents

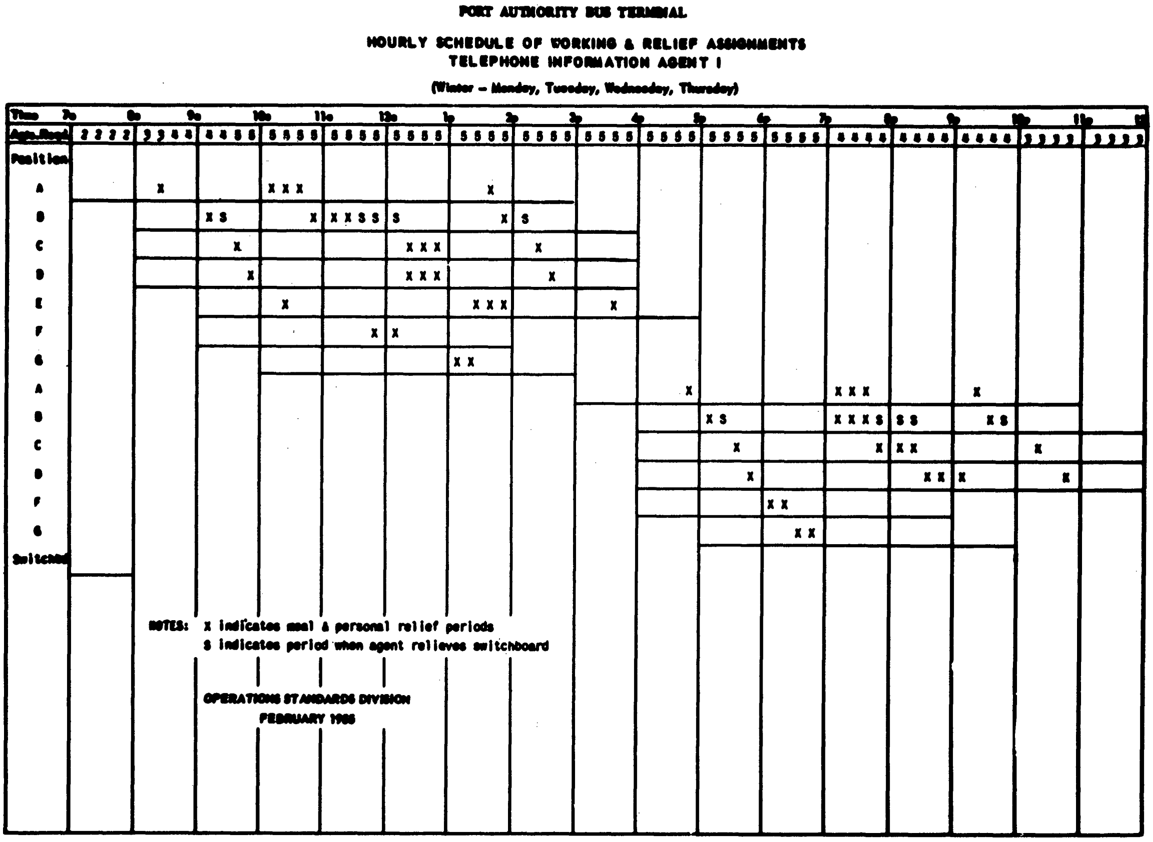

Figure 12

required on duty to provide service for the forecasted traffic. The 15 minute interval was selected because it is the personal relief period of the agents. The bars on the chart indicate the hours of duty for each agent and you will note we utilize both 8-hour and 5-hour agents. The use of 5-hour agents could possibly be of interest. These agents are paid at the same pay scale as the regular 8-hour agents with total pay proportionate to hours worked. We find this type of agent very easy to recruit and their absence factor is substantially lower than the average factor on the full-time agents. It is possible that the reason for this lies in the fact that a large majority of these 5-hou agents are housewives with families, who find it quite convenient to work duri the peak hours of 10 a.m. to 3 p.m. and the added income to the family is important. The utilization of 5-hour agents contributed to the manpower savings effected by this study.

In developing the schedules, the study group encountered the usual personnel problems and cooperated with Bus Terminal management and the Personn Director in determining whether the schedules should be the fixed or rotating type. Then began a difficult trial and error job of fitting the tours in to meet requirements with a minimum of scheduling loss, while at all times maintaining adequate relief to cover forecasted absences and relief periods. Fortunately for us, one of our engineers, early in the process, came up with the idea of using a peg board to play this game on. Strips were pasted at the top showing hours of the day and agent requirements in the 15-minute intervals taken as the distance between two holes. At the bottom, overs and unders could be shown. Narrow plastic strips were made representing 5 and 8-hour tours and these in turn were drilled with holes, again representing 15-minute intervals. The plastic strips were positioned on the peg board by means of small rivets. Some of the rivets were painted white to indicate personal relief and meal periods, and others were painted black to simulate work periods at the PBX switchboard. By means of this gadget, it was possible to juggle the strips in either direction and by moving the rivets from hole to hole to stagger relief and meal periods in accordance with the agent requirements at the top of the chart. It is difficult to estimate how many man-hours of scheduling labor were saved by means of this simple tool, but they were considerable. This procedure was followed until a complete set of schedules covering all conditions for one year were prepared.

You probably wonder why we went through this tedious trial and error method of setting up schedules when it possibly could have been done through the development of mathematical formulae for the use of high speed computers. We considered this approach very carefully, but determined that due to the small size of the group and the relatively small number of schedules required, the hand method was the more economical. However, we are presently engaged in a project involving the scheduling of toll collectors at the Hudson River Crossings. In this case, we are talking in terms of hundreds of toll collectors, dozens of schedules and very sensitive seasonal variations of short duration. In this problem we are using linear programming techniques, designing mathematical models which we hope will produce answers in whole numbers since it is rather difficult to schedule one-quarter of a man. If successful, we will look to the high speed computers to do the mechanical simulations of the schedules, now done on the peg board.

As a further refinement in our scheduling process we developed individual cards for each agent as shown in Figure 13 next slide. The supervisor of the shift consults her master schedule showing the number of agents required for her tour. She then refers to the Gantt scheduling chart and selects the position cards applicable to that day and season. As each agent comes on duty, the supervisor hands her a position card. This card informs the agent of her duties throughout the tour. For instance, the agent receiving this particular card proceeds to position B - the 14 positions have been lettered for ease in assignment. You will note that this card is also good for the evening shift. The card indicates that the agent on the a.m.

THE PORT OF NEW YORK AUTHORITY
POSITION RELIEF CARD

POSITION B

DAY TOUR

DAY	START	1 ST BREAK	MEAL BREAK	2 ND BREAK	CLOSE
ALL	8:00 AM	9:00	10:45	1:45	4:00 PM
		RELIEVE SWB			
		9:15	11:30	2:00	

EVENING TOUR

DAY	START	1 ST BREAK	MEAL BREAK	2 ND BREAK	CLOSE
ALL	4:00 PM	5:00	7:00	9:30	12:00 PM
		RELIEVE SWB			
		5:15	7:45	9:45	

Figure 13

shift starts work at 8 a.m. and receives her first 15-minute break at 9 o'cloc Upon completion of her break at 9:15 she relieves the PBX switchboard operator for 15 minutes and then proceeds back to her assignment at position B where she remains until 10:45 - her meal break. You will then note that she again relieves the PBX operator at 11:30 for a 45-minute meal break, after which she returns to position B and remains there until her second break at 1:45. Again, she relieves the PBX operator for 15 minutes and then returns to position B for the balance of her shift. Both supervisors and agents have found these cards to be very helpful, since the guess work in providing reliefs has been eliminated.

Results

Of necessity, I have rushed through this case history. Some of the detailed observations and analyses connected with the project have not yet bee mentioned. By now you may wonder whether it was all necessary and worthwhile, so let's look at the results.

In the first place, the study permitted significant manpower reductions amounting to 20 man hours per day in the summer season and 56 man hours per day in the winter - about 9% and 25% respectively, as compared to the manpower before the study. Financially, the project has been producing savings at the rate of $25,000 annually since its adoption in 1955. The cost of the study was $8,000. More important, however, than the financial results has been perhaps the better control over service made possible through the development of manning tables based on traffic load and service standards instead of operating on judgment and rules of thumb. Forecasting tools have been provided which should be effective for a long time to come and curves of service versus cost are definitely established so that policy decisions on changes can be quickly and accurately analyzed. The morale of the agents and supervisors has increased. The quality of the service rendered has improved; so that everyone is reasonably happy - as happy as they can be in a congested bus terminal.

Other Results

You may justifiably suspect that I have selected one of our best jobs to present to you in detail. Actually, however, I haven't. The telephone information study with its continuing payoff of $25,000 per year for a one-shot study cost of $8,000 is an average one of its type. In the remaining few minutes let me mention a couple of our other studies.

There was one quck study, taking only about one man-week of work which resulted in a saving to the Port Authority of $130,000. From the standpoint of return on investment, this is perhaps the most spectacular of all our jobs so far. It concerned the prediction of multiple vehicular breakdowns in the Lincoln Tunnel tubes after the third tube is opened. This event is scheduled for May 25, 1957, less than three weeks from today, after some 5 years of construction.

The point of the analysis was the need for a third garage to house towing equipment for this third tube. The analysis indicated that the two existing garages would be adequate, and by removing the third garage from the construction, the appreciable saving was made. The cost of the proposed garage was high because its construction required excavation of 65 feet of rock.

Greater savings than this, however, have been enjoyed annually as a result of O.R. studies of policing of the Hudson River tunnels. One of these studies was concerned with the foot patrol of the tunnels, which has been the practice since the Holland Tunnel was opened in 1928. The study is of interest since it compares with certain wartime O.R. jobs where the important contribution of O.R. was more in a change in the measure of effectiveness than in the analysis. A wartime example of this type of O.R. job is the setting of depth bomb fuses, where the measure of effectiveness was changed from one of maximum destructive power to one of greatest probability of damage. The optimum settin of the fuse was changed radically from 100 feet to about 25 feet by this change in measure, so was its effectiveness. Submarine sinkings increased several fold when the change was made and the Germans believed the Allies had a new secret weapon. In our case, the measure for tunnel policing was changed from one of equal post areas to one of minimum distance to occurrences within the tunnels requiring police attention. This change in measure brought to light the fact that occurrences were not uniformly distributed throughout the tunnel but instead were concentrated with 70% in the exit half of the tunnel. By reapportioning tunnel areas, two posts were eliminated and yet the overall effectiveness was increased. While not a several fold improvement as with the bomb, the posts eliminated have yielded savings of about $50,000 per year for the past four years.

A part of the study of tunnel policing was concerned with alternative means to foot patrol, and it resulted in the substitution of automotive patrol for about six hours at night when one tunnel lane could be closed. It was predicted in the study that six police officers in three vehicles would reach occurrences as quickly as twelve men on foot distributed through the tunnel. In this case, top management was not convinced until a trial had been held of the two systems in competition. Results were interesting. Out of 22 occurrence during the test, the foot patrol won in 10, the automotive patrol won in 11 and one was reached simultaneously - in a dead heat. Thus the plan was sold, and it has been yielding net savings in police salaries of about $100,000 a year after deducting the automotive costs.

Other areas of past O.R. work include elevator operation, bus platform operation, bus terminal design, toll collection, lobby information services and others. Present O.R. work in process includes personnel scheduling by computer, automation of toll collection, increasing traffic flow in tunnels, and developing the optimum police staffing for an entire facility. This work is being accomplished with an O.R. group varying from about two to ten persons with from one to five years experience in O.R.

In conclusion, I would like to summarize: Service, like science, has come to be a key attribute of American industry. Not only have the service industries themselves grown apace, but also the service operations in productic industries have likewise grown. In running these service operations, we manage face the ever present problem of relating quality of service to the cost of service, of improving both and of balancing one against the other. These are not all embracing problems but instead are often of limited scope. Operations research, in bringing science more deeply into the service problems, is howeve making a major contribution to our abilities to plan and control these operatic for the maximum benefits to our companies.

ORGANIZATION AND FUNCTIONS OF AN OPERATIONS ANALYSIS GROUP IN A CHEMICAL COMPANY

Helmut W. Schulz
Associate Director of Development
Union Carbide Chemicals Company

When Professor Thrall invited me to participate in this symposium, I demurred, for I am not a practitioner in operations research, but merely a chemical engineer with an interesting assignment: to develop an operations analysis group for the evaluation and application of these mathematical techniques to the needs of a research and development organization. I approached this job with some skepticism, remembering the initial splash and rapid attenuation of other glamorized fads. I could sympathize with the production manager with 25 years of experience built into the seat of his pants, who winces when a bright young man with a computer offers to solve what he gleefully labels the "production problem".

However, I am a reconstructed skeptic, and I believe that operations analysis, as we prefer to call it, can be an important aid to industrial management. This new discipline may be loosely defined as the application of quantitative analysis to complex technological and business problems which require a sequence of interdependent decisions to obtain an optimum result. The complex situation may often be represented by a mathematical model which furnishes quantitative estimates of the consequences of possible alternatives, to facilitate the decision making process.

Although the concept of basing judgment on quantitative data is not new, there is one important factor which justifies the current emphasis on these mathematical techniques. This is the recent development of the high-speed electronic data processing machine. Such computers, with the capacity of performing more than one million operations per second make light of the mathematical burden that would have bogged down any operations researcher who had to depend on his log tables and slide rule. These so-called electronic brains offer no relief from the painful process of thinking, but the very act of addressing meaningful questions to the machine can in itself stimulate thinking.

My subject today is primarily a case study of how one operations analysis group is organized, how it fits into the corporate structure, what sort of functions it performs, and how these services are utilized.

ORGANIZATION

The Operations Analysis section of the Development Department of Union Carbide Chemicals Company is a small staff group which was formed late in 1954 as an arm of the Development Department. The Development Department is a laboratory organization of four hundred people concerned with product and process development in the fields of synthetic organic chemicals and resins.

The Operations Analysis group came into being to consolidate and formalize grass roots activities which had been initiated by several individuals in the Department and strongly supported by our Director. The centering of these activities in one group brought together three chemical engineers, two chemists, a physicist, a mathematician, a statistician, and four technicians. All members of the group have a fair background in mathematics and have been exposed to a variety of computer training programs. We have also found it very helpful to engage the services of consultants such as Professor Merrill Flood, now here at Michigan, in the field of Operations Analysis, or Professor Whitwell, of Princeton University, in the field of Experimental Design. These contacts were not only stimulating but invoked the principle of learning by doing. It has been largely a case of old dogs learning new tricks, but this offered the important advantage of thorough familiarity with the work of the Department and the operations of the Company. Expansion of this section is predicated upon demonstrated demand for its services, and today the backlog of work in many of its functions is such as to justify an immediate doubling of the staff, preferably through the hiring of trained specialists.

In the realm of hardware we have progressed from an IBM 602A accounting machine, to a CPC, to a 650, and are now looking forward to a Ramac 650 and the availability next year of a 709. This latter machine will serve the Corporation as a whole, but we are already working on a problem which will require this advanced computer.

The position of this group in the Development Department of the Company has an important bearing on the nature of the problems handled. Its primary role is to facilitate, augment, and evaluate the technical work of the Department. This is done largely through such functions as experimental design, statistical analysis of data, mathematical engineering, electronic data processing, and technical computation. The realm of operations analysis, on the other hand, is primarily concerned with technological and business problems, which are generally of Company-wide scope. Our interest here is confined to the development of mathematical models and machine solutions which are then handed over to the appropriate operating department for implementation. This corresponds to the traditional role of the Development Department in developing new processes which are then graduated from the Laboratory to the Plant.

FUNCTIONS

The work of the Operations Analysis section may thus be compartmented in terms of distinctive functions which are the primary responsibility of separate groups in the section.

Development of Operations Research Techniques

This group is principally concerned with the development of mathematical models and machine programs which will be useful in the solution of Company-wide problems that are particularly amenable to the Operations Analysis approach. The group is also concerned with the application of these models to actual operating problems so that their utility can be more widely assessed and appreciated. Inasmuch as solutions of this type are very likely to impinge on managerial prerogatives, there can be considerable sensitivity or even resistance toward accepting ready made solutions from a staff group, no matter how expert or objective. For this reason we have found it desirable to approach actual problems by forming Operations Analysis teams of four or five members, including representatives from both the Operations Analysis Group and from the departments that will be involved in implementing the solution. The efforts of these Operations Analysis teams are coordinated by a Company-wide Operations Analysis Steering Committee on which most major Departments are represented. This Committee helps to select suitable problems, appoints the working teams, arranges for effective implementation, and undertakes to appraise the results.

By way of illustration, I might mention two broad problems on which the Operations Analysis group has worked. The first might be termed the Monitoring Problem, as applied to the monitoring of product quality, of manufacturing costs and of financial return. The objective here is to compare performance data statistically against preestablished or continuously adjusted standards, so as to single out those products and processes for special attention which violate the established limits. Management can then concentrate its efforts on the exceptional cases. After a period of pilot operation of the monitoring system, including the issuance of model reports, it was turned over to those groups which are directly concerned with its maintenance and use. The monitoring of product quality is now administered by the Quality Control Laboratory, the monitoring of manufacturing costs by the local Plant Operating Departments, and the monitoring of profitability by the Financial Control Manager of the Company. Another and far more ambitious project might be termed the Assignment Problem and defined as follows:

For any given sales pattern of product mix and customer distribution, utilize the available raw materials, the existing production and storage facilities, and the appropriate transportation means so as to maximize net income, not for any given plant but for the Company as a whole. Considering the fact that we must include over 50 different chemicals if we wish to represent 90 per cent of our sales volume, that our production facilities are located in seven different plants and that we would like to differentiate something like 100 different customer areas, it will be appreciated that the interactions attending sequential decisions make for a very complex situation. However, we are much encouraged by the progress we have made with a pilot model which includes five products, five plant locations, and ten customer areas. The principal purpose of this pilot model is to help define the nature of the input data required and the type of restrictions that will be encountered. An indication of the economic incentive to this sort of project is afforded by an earlier transportation study which forecasts a potential saving of more than a million dollars a year in the distribution and inventory costs of but one of our major products.

Experimental Design and Statistical Analysis of Data

The principal business of the Development Department is to carry out applied research, process development and pilot plant studies. In view of the continuing manpower shortage, anything that will increase efficiency of experimentation, giving more data for a dollar or more bang for a buck, is of real interest. Statistically designed experimentation is not applicable to all types of laboratory projects, but where applicable it will permit experimental coverage of process variables with approximately half the number of experiments that would be required by the classical approach. Concomitantly, statistical analysis of the data so obtained will permit a more penetrating interpretation of the results, particularly as regards the interaction of variables. Here again, use of this mathematical tool will not prove a remedy for sloppy or unimaginative experimental work. It will, however, call for thoughtful planning before rushing into the laboratory, and it will also afford a measure of the inevitable experimental errors.

The use of experimental designs is not imposed upon the experimental groups and only a fraction of our major projects are based on statistical designs. It is therefore still too early to definitely assess the potential value of this approach. However, I believe that the demand for this service will grow as the experimental staff becomes familiar with its advantages.

Mathematical Models of Reaction Mechanisms and Converter Dynamics

The construction and use of such models might be termed mathematical engineering or mathematical experimentation. It really is little more than theoretical chemical engineering, augmented and facilitated by machine computation. Its effectiveness is heavily dependent upon the availability of sound primary data, and for this reason it can often best be applied to data derived from carefully executed experimental designs. Experimental data can be represented by differential equations which may be solved to indicate optimum ranges of variables for experimental verification.

Even before the actual experimentation starts, it may be possible to calculate the most propitious converter geometry based upon considerations of heat of reaction, heat transfer, and fluid flow. For this type of analysis we have access to an analog computer which permits simulation of the converter dynamics once the reaction kinetics are reasonably defined.

Economic Appraisals of Proposed Processes

In considering research and development programs, it is frequently necessary to decide between three or four alternative routes leading to a desired new product. Not only should experimental effort be concentrated on the most promising alternative, but it is desirable to assess the magnitude of the expected pay-off in order to determine how ambitious an experimental program may be justified. The purely quantitative factors in such an appraisal must be tempered by the probability of success, and this calls for judgment born of experience.

The preparation of an economic appraisal requires the postulation of a process and plant. In some cases the raw material economics play such a dominant role as to immediately indicate a logical choice; in others, high investment requirements for corrosion resistant construction or specialized equipment may prove decisive; again, it may be profitable to know what chemical efficiencies must be attained to make the process economically attractive. In general the results of such appraisals are expressed as the annual rate of return on the required investment for a given production level and sales price; or the sales price may be calculated that will afford a satisfactory return. This activity fits logically into the Operations Analysis Section, although little computer hardware is required beyond a desk calculator and a ten inch slide rule.

Management of Technical Information

The rate at which new scientific and technical data are being generated is ever accelerating, and the problem of rapid, systematic, and comprehensive access to this wealth of information is of major concern to any technical organization. Three sources of information may be differentiated: the scientific literature, domestic and foreign patents, and internal reports and correspondence. In the case of a large chemical company such as Union Carbide Corporation, the internal data may represent the fruits of an annual experimental expenditure of the order of fifty million dollars, contained in a variety of publications from more than a score of Company laboratories.

We have developed a punch card system for the indexing and retrieval of technical information based on a superimposed random code. This system is being applied to all internal reports and certain selected patents. It merely identifies and locates the document containing the desired information, which must then be obtained from the library files. Ultimately, we foresee the need for a mechanical system such as the Eastman Minicard System, which would also provide microfilm storage of all documents, so that copies of desired items can be obtained as part of the searching process.

The problem of adequate coverage of the scientific and patent literature is so immense, that it can be adequately attacked only by the major technical societies and the United States Patent Office. Such official coding and indexing is of course under study, and we are content for the interim to secure comprehensive coverage by assigning a professional searcher to Washington where he may have access to the literature and patent files of the United States Patent Office.

Electronic Data Processing, Machine Computation, and Programming

This group is essentially a service group to the other groups in the Operations Analysis Section. It formulates problems in terms of specific methods of numerical analysis amenable to machine solution, writes machine programs, debugs them, and supervises machine operations. It also provides this service on an open shop basis to other departments who have no programmers or computer personnel but generate data processing or technical computation work. This group also performs a number of routine data processing operations such as those pertaining to cost accounting on experimental projects in the Development Department.

In conclusion, I should like to pay tribute to the professional job being done by a spirited group of largely self-taught operational analysts. The Development Department considers the technical functions of this group of demonstrated value to the more effective and efficient functioning of its experimental staff. We believe that an even greater potential exists in the application of operations analysis techniques to managerial problems, the scope and complexity of which is measured by an annual sales volume of half a billion dollars.

SOME ASPECTS OF THE AIR TRAFFIC CONTROL PROBLEM

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The subject of air traffic control, particularly where air collision is concerned, is topical at this time. Mr. Edward Curtis, Special Assistant to President Eisenhower for Aviation Facilities Planning released a preliminary announcement of his findings last week. The Air Transport Association and the Airline Pilot's Association has just announced some traffic rules of their own for the New York, Washington and Chicago triangle to be effective July 15 this year. I therefore feel that this gathering might be interested in a few generalities about the air traffic control problem as well as the results of one or two limited operations research studies.

As you are well aware the electronics industry, airlines and the legislature have been concerned about air traffic problems including collision, navigation and landing for many years and now are looking hard at the air collision problem. Industry seeks to provide the best possible equipment and associated technical advice within certain ill defined cost limitations, the airlines seek the best possible safety record, aircraft utilization and revenues, the legislature is the guardian of the public's safety and overall fiscal interests. So far, they have concentrated upon preventing collision situations from arising by voluntarily regulating traffic movements between terminals during instrument flying conditions (IFR) and by plotting and directing movements in the vicinity of terminals with the help of radar and radio. Let us briefly review some simple fundamentals.

The primary method of traffic control today deals with aircraft flying between terminals, i.e., "En route" traffic. Control is effected in several detailed ways and basically relies upon data relayed from the aircraft cockpit to terminal control centers, this can include present position, direction of travel, altitude and intended position. The relayed data are displayed in control rooms and are observed by controllers who rely upon judgment for identifying dangerous situations and who relay instructions, directly or otherwise, to the aircraft.

En route traffic could also be controlled by data relayed from unattended surveillance radars located at suitable intervals along the airways. That it is not presently controlled in this way is due in no small measure to the expense of installing the surveillance radars, since control of low flying aircraft requires many more radars owing to the earth's curvature. But the C.A.A. is now buying radars for this purpose for use in the next few years.

The terminal areas, so described because they originate and receive traffic, are determined by the surrounding population using them. The surrounding air space becomes increasingly congested as the traffic converges on the terminal especially when there are several airports in the terminal area. A surveillance, or mapping, radar can plot the geographical position of aircraft to ranges of 50 miles approximately, the latter being the limit of the terminal area. The surveillance radar, therefore, is very useful to traffic control in terminal areas, as far as the kinematics of aircraft spacing are concerned. However, it currently fulfills a purpose secondary to that of the "en route" control system, acting as a policeman watching traffic moving into the terminal area for any violations of safety rules. A few major terminals also use surveillance radars to direct departing aircraft into the civil airways. The rate of aircraft landings decreases sharply when weather deteriorates. Terminal areas then become severely congested and loiter areas are provided where aircraft fly around small closed circuits until the reduced landing rate can handle the waiting traffic. Figure 1 is a sample airway's chart depicting holding areas.

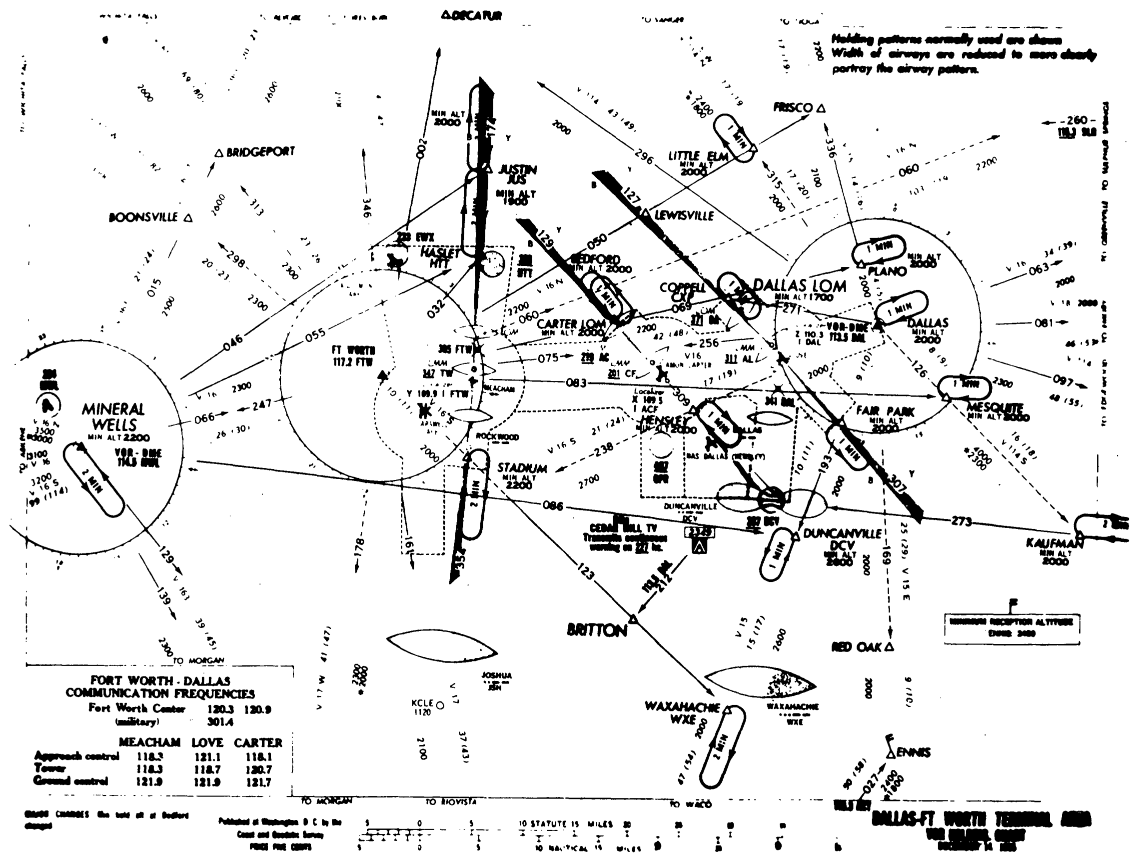


Figure 1

I will next describe very briefly the broad classifications of traffic and the extent of control. For the purposes of this discussion, air traffic can be classified as Common Carrier, i.e., licensed carriers of passengers and freight; General Aviation, i.e., aircraft flown by private business and individuals; and Military Aviation. En route general aviation and military aviation mostly fly from point to point and not along doglegged routes in a manner of the common carrier. General Aviation or that owned by private individuals and private business makes up the majority, but the military aviation fleet is large, is interspersed with other traffic all over the country and predominates in several areas.

Having defined the different classes of traffic we can proceed to describe very briefly the routine presently followed for air traffic control and the extent to which it applies to the foregoing.

Under present procedures, when the weather does not restrict flying activity (i.e., ceiling and visibility are above certain minima) air traffic is controlled on a voluntary basis. Thus any aircraft may fly under instrument flight rules, be assigned, from the ground, a flight altitude, report over airway check points, and have its whereabouts and its space relationship to other controlled aircraft always known. Or, the pilot may simply file a VFR flight plan with the proper authorities, indicating his intention to cover a certain route, subject to no further control. The geographic location and altitude en route might be inferred, but are not known. At the extreme, an aircraft will simply take off, fly, and land, with no ground control or notification of intention to fly. Under visual flight conditions, aircraft following visual flight rules can become mixed with aircraft following instrument flight rules.

The general practice presently favors control, as described above, of common carrier and military flights for at least part of their time aloft, even in clear weather. The greatest amount of control occurs in terminal areas. Apart from local flying the majority of general aviation fly after filing VFR flight plans, and are effectively uncontrolled, also. The proportion controlled today does not exceed 15% of the total number of movements.

On the question of overloading, air traffic movements have doubled in the past five years, achieving this in half the predicted time (Reference 1) and they will continue to increase in the next decade accompanied by an abrupt upward change in air carrier aircraft speed and altitude (See Fig. 2). The latter is significant to the general flying public for safety reasons, since the air carriers now move about one half of all long distance travellers.

Year	Type	% of Fleet	Range of Cruising Speed	Range of Cruising Altitude (usual practice)
1956	Small: DC-3 Convair Series Martin Series Viscount	57	150-300 Kn	5000-12,000 ft. 10,000-20,000 ft.(Viscount)
	Medium: DC-4 DC-6 Series DC-7 Series Constellation Series Stratocruiser	43	150-300 Kn	5,000-10,000 ft. (DC-4) 10,000-22,000 ft. (others)
1965	Small: Piston Types as 1956 Viscount, F-27	15 15 } 30	150-350 Kn	5,000-12,000 ft. (piston) 10,000-25,000 (turboprop)
	Medium: Piston Types as 1956 Electra DC-9, Convair 880, Comet IV	 11 30 } 55 14	 250-300 Kn 350 Kn 480-550 Kn	 10,000-22,000 ft. 10,000-25,000 ft. 20,000-35,000 ft.
	Large: DC-8 Boeing 707	15	480-550 Kn	20,000-35,000 ft.

Figure 2

Thus far, I have described the principles of traffic control, the broad classes of traffic, the extent to which traffic control is used and future changes in speed, altitude and number of movements.

We are seeking information on the number of collisions, location of collisions and the qualitative effectiveness of remedies.

Data on actual and potential collision situations are hard to obtain. In 1952, the military reported approximately eight mid-air collisions per month, exclusive of formation flying accidents (Ref. 2). A recent airlines study (Ref. 3) reported approximately 1500 near misses a year. By 1965 the number of general aviation movements is expected to double as will the number of air carrier movements, although in the latter case the number of aircraft may not increase. The number of military aircraft can be assumed to remain unaltered. Helicopter movements will increase. Assuming that movements in major traffic areas will double by 1965 and no change in aircraft speed or control, random distribution analyses predict that the collision expectancy will be quadrupled.

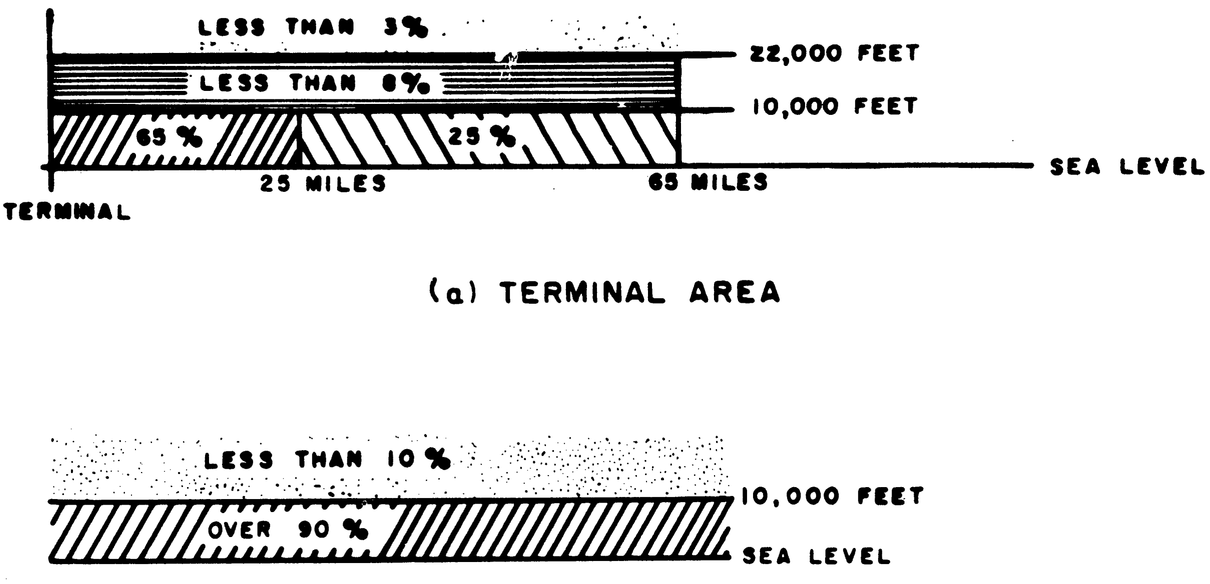
The Bendix Aviation Corporation has obtained information which is quite interesting and which takes some account of moderate improvements in ground control. The findings will be briefly described here as follows:

Two separate air traffic models were synthesised. Traffic instantaneously airborne was estimated for a typical 1965 summer day in New York and Washington terminal areas--about 125 aircraft within 30 miles of each. A peak estimate was also made for IFR conditions in 1965--about 150 aircraft on the NY-Washington airway which is 10 miles wide.

The traffic in each model was distributed and directed according to certain rules such as, traffic control, procedure, type of traffic, type of aircraft and popular routes.

The traffic speeds were then rationalized into a few categories and aircraft positions were compared for potential collision on the basis of proximity alone, irrespective of direction of travel. The instantaneous collision probabilities were then estimated on the basis of random motion in a critical volume and the results were then integrated over the day and over the year to yield the annual probability of collision situations arising.

These analyses, admittedly rudimentary, predict 1500 annual potential collision situations arising in the New York terminal area in 1965. (A collision situation arises when two aircraft get closer together than the minimum distance required for an avoidance maneuver, irrespective of whether they will actually collide). These collision predictions although inexact are meaningful in indicating the approximate nature of the problem. Figure 3a and b, respectively, illustrate the approximate distribution of collision near a large terminal such as New York City and "en route" between two large terminals such as New York and Washington.



(a) TERMINAL AREA

(b) ENROUTE

Figure 3

65% of all collision situations near the terminal will occur below 10,000 feet and within 25 miles. Clearly terminal control systems, such as surveillance radars have their place.

Over 90% of the collision situations "en route" will occur below 10,000 feet. Most of the aircraft below this altitude are low cost and the owners can only afford simple and easily maintained equipment, a factor greatly favoring very simple methods of traffic control such as the "Fixed Block" system.

The speed disparity between different types of aircraft, particularly in the numerous General Aviation category, increases as time goes by as will be apparent from Fig. 4, thus greatly increasing traffic control problems in the "en route" areas. Suggestions have been made, as previously indicated, to restrict the speed in selected zones and altitudes. Fig. 5 is typical of contemporary suggestions and is not unreasonable since high speed and high altitudes are largely synonymous. Speed and zone restriction are excellent palliatives, not cures; since speed, altitude and traffic density are constantly increasing and emergency loiter duration decreasing.

Type	% of General Aviation Fleet	Range of Cruising Speed	Range of Cruising Altitude
Small Private, Group 1 Cessna 140 Piper Tripacer, etc.	15	60-100 Kn	Under 10,000 ft.
Small Private, Group 2 Bonanza Navion T-34 Trainer, etc.	25	100-150 Kn	Under 10,000 ft.
Light Twin, Group 1 Aero Commander Twin Bonanza Cessna 310, etc.	29	120-180 Kn	Under 10,000 ft.
Light Twin, Group 2 Beech Super 18 DC-3, etc.	15	120-180 Kn	Under 10,000 ft.
Light Twin, Group 3 Beech Twin Jet Turboprop Twin (Hypothetical)	11	250-350 Kn	10,000-22,000 ft.
High Performance Small Jet Transport	5	about 500 Kn	25,000-40,000 ft.

Figure 4

The same is true for virtually every method of reducing collision risk, including limiting the use of certain restricted routes to highly sensitive aircraft such as large civil passenger aircraft. A contemporary user's association recently pointed out that many private users will soon be flying at high speed and altitude with small aircraft.

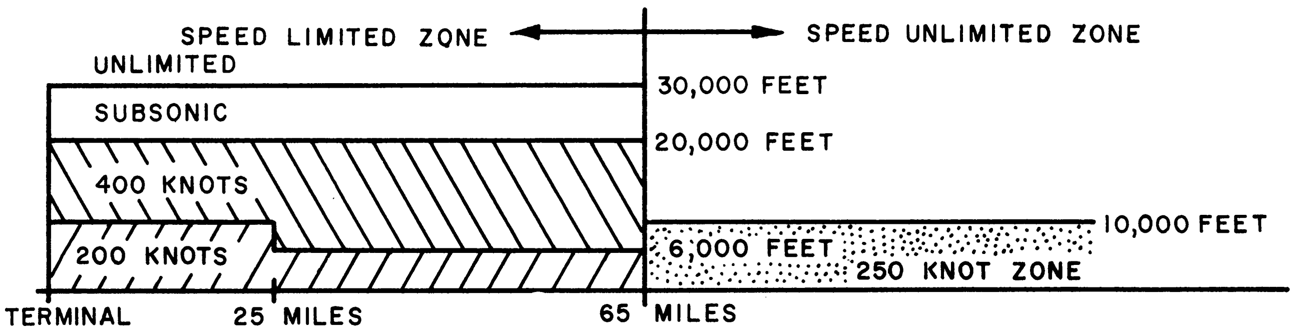


Figure 5

Natural vision, the oldest form of collision warning and avoidance is of course entirely self contained within the aircraft and has already been mentioned. It is referred to amongst pilots as "See and Be Seen". Human vision supported by memory is ill equipped for collision avoidance in the air at present day high speeds and is useless in clouds. Additionally, the probability of detection is limited by the pilot's alertness and, to a limited extent, as will later be seen, by his azimuthal angle of view. On the other hand this method may be less susceptible to saturation than the others and places the command responsibility closest to the source of danger as well as to the place for emergency corrective action. For this reason, theoretical self contained systems are favored above others amongst pilots. The fundamental inadequacy of unaided vision and the possibility of using electronic substitutes following the same principles will be seen from the following work by Dr. J. S. Morrell, who is associated with the Radio Division of the Bendix Aviation Corporation.

Figure 6 shows the probable direction from which a collision threat will emerge. The analysis is based upon random heading distributions and does not take into account the effects of Air Traffic Control rules or procedure. The Table shows by far the greater majority of collision situations develop in the forward hemisphere, a consoling thought to pilots unable to see behind them. The results are not unduly sensitive to airspeed.

Figure 7 defines the terms for the two-dimensional collision situation.

Figure 8 illustrates the collision prediction geometry. The only methods for determining the probability of a collision situation arising are, measuring the rate of change of bearing angle, i.e., $\dot{\theta}$, or the rate of range rate change, i.e., $\ddot{r}$.

RELATIVE ENCOUNTER FREQUENCIES

Three types aircraft: 160, 200, 240 knots.

Round trips, same route.

Same departure frequencies.

Type of Encounter	Percent Encounters Involving Each Type Aircraft			
	Slow	Medium	Fast	All
Overtakes	0.0	2.5	5.8	8.3
Is Overtaken	6.6	1.7	0.0	
Head-on	67.8	60.3	55.7	91.7
Total	74.4	64.5	61.2	100.00

There are eleven times as many head-on as head-to-tail encounters.

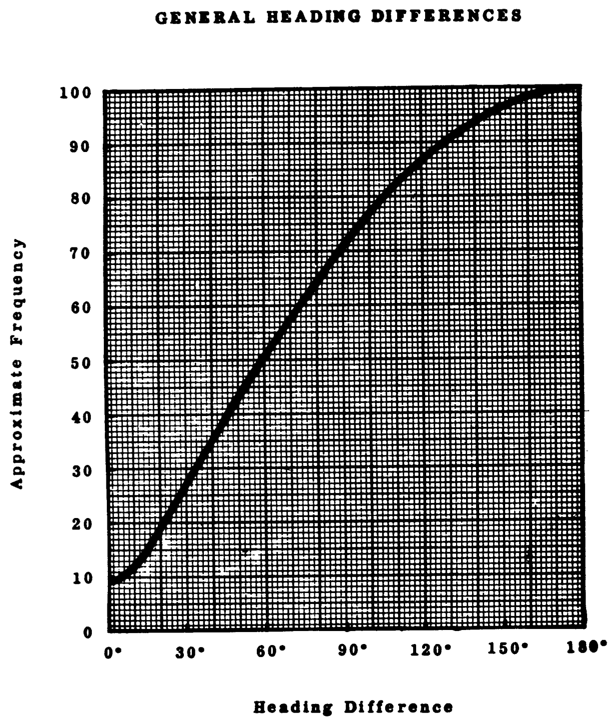


Figure 6

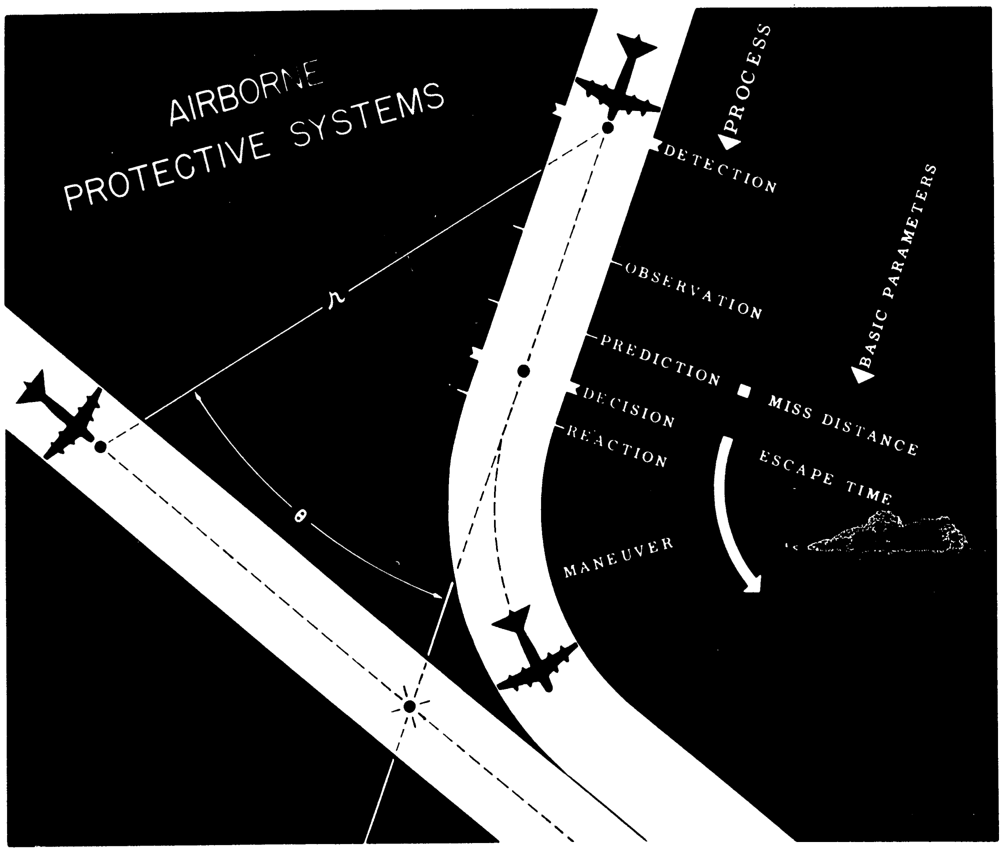


Figure 7

COLLISION GEOMETRY.

COOPERATIVE SYSTEM

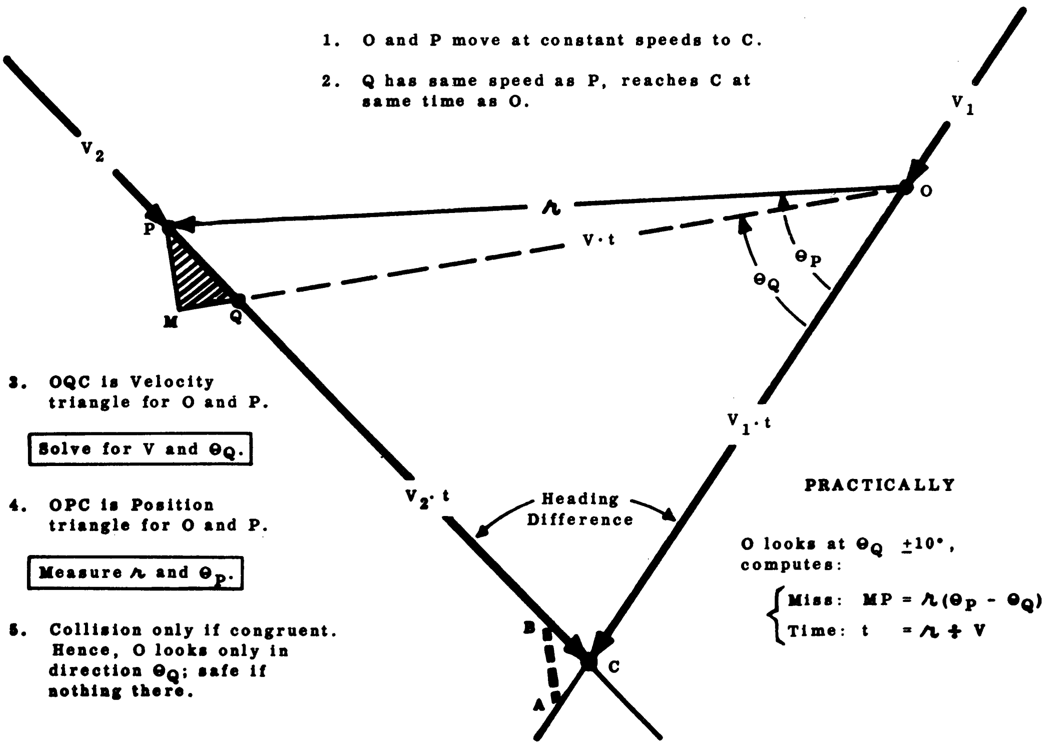
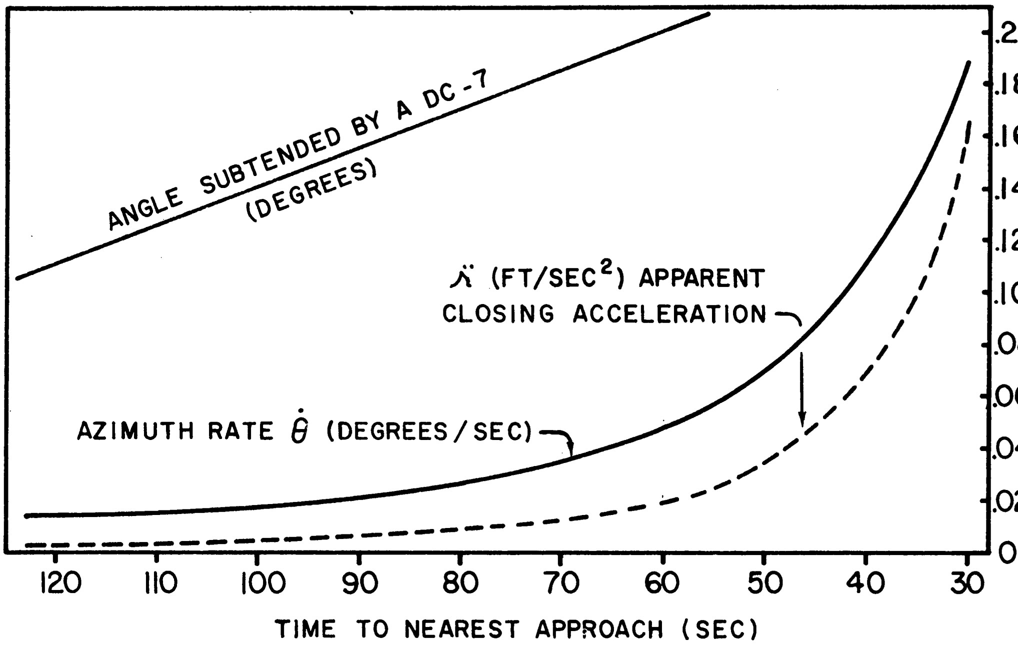


Figure 8

Figure 9 provides a numerical example of Fig. 8. The relative speed is 300 knots or 500 feet per second. When the miss distance is 1/4 mile neither the range rate change nor the angular rate exceeds 0.20 feet per second or degrees per second respectively at times greater than 30 seconds before closest approach. Three points should be emphasized. 1) A fairly violent maneuver would in any case be required to produce a 1/4 mile miss distance if the aircraft were colliding. 2) The eye is quite incapable of sensing these values. 3) The ability of any device to measure to these accuracies has yet to be demonstrated. 4) Even devices measuring $\ddot{r}$ and $\dot{\theta}$ with sufficient accuracy would be useless because the values quoted would be exceeded by normal perturbations in airplane speed and heading due to atmospheric turbulence and normal airplane instability.



COLLISION DERIVATIVES
AIRSPEEDS: 300 AND 360 KNOTS
RELATIVE AIRSPEED: 300 KNOTS
MISS DISTANCE: 1/4 N. MILE

Figure 9

The preceding discussion emphasizes the extreme difficulty of producing a substitute following the principal of human vision. It also leaves us with the sobering realization that it remains to be proved whether at modern aircraft speeds the "See and Be Seen" method will avoid a collision once the situation has started to develop.

I wish not to convey the impression that airborne devices are totally inadequate but that much more analysis of this problem is needed to find a solution. For example, apart from instrument error two aircraft in close proximity can exchange data on altitude above the ground and maneuver accordingly, depending upon their proximity and heading which can be radioed from one aircraft to another provided instrumentation accuracy can be made adequate in the future.

Before summing up I would like to recall to your attention that, at this time and for several years to come, the majority of traffic cannot be controlled from the ground to avoid collision, many non-air carrier operators presently resent the suggestion. The same is true of airborne methods of collision prevention.

Figure 10 now summarizes the mid-air collision problem:

1. Ground based traffic control is essential. It will reduce the changes that risk situations will occur and will seek to plan, direct, monitor, and correct all flights.

2. An airborne system is essential to reduce, by maneuvering the aircraft, the chances of collision once the risk situation has occurred.

3. As regards airborne devices there are three fundamental systems: "See and Be Seen", which is inadequate; self-sufficient systems using ranges and bearing data, which are presently inadequate; cooperative systems which presently offer promise of a solution and have yet to be proven. The Bendix Radio Division has a contract from the U.S. Air Force to consider aircraft proximity warning and collision avoidance techniques.

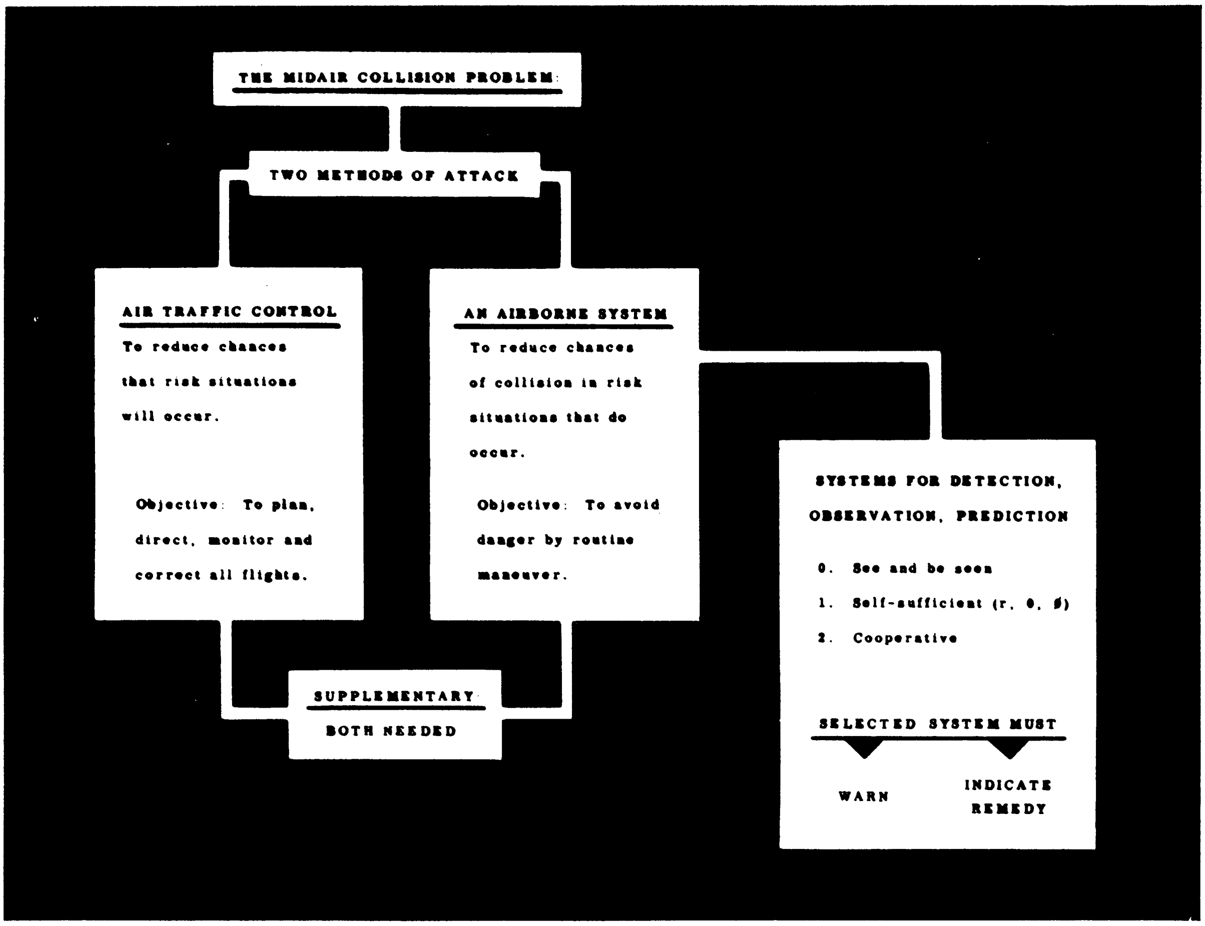


Figure 10

The problem presented to you today is typical of many and operations research has a place in it. None of the solutions mentioned is adequate, the problem is fluid, constantly changing in magnitude as well as character. The rigid analytic approach which does not look at the entire problem both as it is today and will be 10 years hence, is usually misleading and should always be regarded with suspicion. Arbitrary legislative approaches must be carefully tempered for similar reasons and particularly should avoid measures which directly or otherwise inhibit remedial research.

The examples presented to you are typical both regarding problems and operations research techniques in the following respects:

1. A vast amount of material on a complex problem is scrutinized; using judgment, the irrelevant is discarded and the remainder reduced to the degree of simplicity needed for quantitative analyses, i.e., the overall future traffic situation has been typified by predictions for 1965 in 2 areas, Washington, New York and en route between these two places.

2. The analyses are conducted with greater concern about the comparative values of different parameters than about the absolute accuracy limits--i.e., the collision estimates. This proceeding is admittedly questionable and considerable caution is required when reaching conclusions.

3. The results of the quantitative analyses are used to reexamine the overall problem in a qualitative manner and thereby to make better decisions than would otherwise be possible, i.e., showing where collisions are most likely to occur and reaching conclusions about surveillance radars, etc.

4. Isolated parts are subjected to scientific analysis and the results are qualitatively interpreted against the background of the overall problem defined in item 1, i.e., the value and limitations of vision, self contained and cooperative methods of avoiding collisions.

5. Lastly and most importantly the whole analysis is intended to provide background material for making high level decisions about types of equipment, research undertakings, and operating policies. The background against which the high level decisions are made is almost invariably wider than that used in the analyses, for example, the amount of equipment or control might be directly affected by Departmental or even National budget considerations, and management invariably makes the final judgment and decision.

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John A. Blum
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Lever Brothers Company

Good afternoon, gentlemen. I have a confession to make to you, it is this: As a renegade merchant with department store experience with experience as merchandising manager for several product lines Lever Brothers Company, I am here today -- gratefully -- more in the acity of student than in the capacity of panel speaker.

My interest in the subject of today's symposium, like your own, n sure, is in trying to learn what practical applications can be made the newer approaches and methods to problem-solving and decision-making my own company. From the title of my talk, it is apparent that my cern lies primarily with applications in the marketing area; there is eady ample evidence, I think, in the experience of many companies here the United States and abroad, and in the professional literature, as to cessful applications of operations research in the manufacturing, dis-bution, inventory control, and general operating areas of business agement. But I think it is also apparent from the title of these re-ks that there is some question in my mind as to the practicality of lication in the marketing area.

Putting the question, "Operations Research: Opportunity for keting Management?" is not just a speaker's device. It is not a torical question. It is a perfectly serious question, and it is one ch I -- among many others -- have been earnestly considering for quite e time. I do not believe we really know the answer to it yet, but I nk we are beginning to identify avenues for exploration with the promise interesting and fruitful results. So I would like to discuss with you a little while today some of the tentative conclusions I have reached this subject. It is my hope that in doing so some of you in this room l be stimulated to intensify your own efforts in this direction, or to tiate new work in the area. For if there is one thing of which I am this moment quite certain, it is that the field of marketing management almost virgin ground for the scientific explorer.

Now, before talking about operations research in relation to the agement of the marketing effort, I think it would perhaps be wise for to say specifically what I have in mind when I use the term "marketing".

In my view, the marketing function begins with the determination as to what you are going to market, at what price, and how you are going to market it. In this definition, after the process of manufacturing has been completed, marketing picks up again at the factory gate or at the warehouse level, and does the job that must be done to make the product conveniently available to consumers and wanted by them. To put it in somewhat hackneyed but nevertheless valid terms, marketing is the job of getting the right goods to the right place at the right time and at the right price, the "rightness" in this series being established by the fact of purchase by the consumer in the free and highly competitive market place. In the marketing of packaged consumer goods especially, this process can be successfully accomplished only on a repetitive basis and, whether we are talking about consumer goods or the products of heavy industry, the process must of course be a profitable one.

In the marketing context thus described, assuming product quality at least equal to that of competition, and given today's highly organized and accessible channels of distribution, the major kinds of problems with which the marketing manager must deal have to do with the creation of consumer acceptance of his product and -- if he is both skillful and lucky -- consumer preference for it. These major problems involve arriving at decisions with respect to questions such as:

1. What is the real sales potential for this product?

2. How fast can I reach that potential?

3. How much should I spend in order to reach it?

4. With a given amount of money available to me over a specific time span, what is the most effective way of spending that money? How much of it should I spend in advertising? in promotion? in field selling?

5. What constitutes a problem area in terms of relative sales in one part of the country as opposed to another?

6. Should I put additional money into areas where my sales are relatively good or should I do exactly the reverse?

7. What is truly my most profitable level of sales and of marketing expense? What marketing strategy is the most profitable for me? What tactics?

As I see it, questions like these have at least two characteristics in common:

1. They all involve deciding between different alternative courses of action or different levels of spending within a given course.

2. They all involve prediction -- prediction as to what the consumer will do if the marketer does this as opposed to that, and they thereby involve prediction as to the relative sales effectiveness and profitability of one marketing action as opposed to others.

This, I submit, is the crux of the matter. I fully recognize the large and increasingly important contribution being made by marketing research to improved decision making in marketing. However, I am not alone in the opinion that the marketing researchers have only begun to scratch the surface, and I believe they can properly look to the newer methods as a logical means of materially extending their accomplishments to date. I believe we have in fact relatively little knowledge as to how the consumer actually reacts under varying conditions, or as to what really makes or changes consumer purchasing habits. We have masses of information in this general area, but we have -- in my judgment -- a very slim basis for establishing the relevance of the data that has been collected to the decisions that must be made.

It is one thing to know, for example, that a given number or proportion of people can play back an advertising message on an aided or unaided basis. It is quite another thing, I think, to know whether there is any meaningful relationship at all between the ability to recall advertising on the one hand and purchasing behavior on the other. Similarly, it is interesting to know claimed or actual consumer likes and dislikes with respect to a product, but such information would be more soundly actionable if we knew more about the significance of consumer likes and dislikes in relation to the purchasing actions of consumers in the market place.

In point of fact, marketing managers are making decisions with respect to these and related questions all day and every day. They are doing so, I believe, primarily on the basis of intuitive judgment and their judgment may well be excellent. However, with the exception of marketing activities such as item advertising at the retail level or in the mail order field where specific response is observable and measurable in relation to cost, our ability to say with assurance that a dollar spent in this particular way today will in fact give us better sales and profit results than the same dollar spent in some other way, is limited indeed, let alone the question as to what an added dollar of marketing expense will do for us.

Every one of us in this room, I am sure, knows of countless instances where company management has been asked to authorize substantially increased advertising budgets, or sales promotion or field selling budget, with little or no knowledge as to what the additional expenditure will actually produce in terms of plus business over a specific period of time. What advertising or sales manager will be so bold as to predict with assurance the volume effect on consumer or company sales if his advertising and promotion budget is doubled, or halved, in one year versus the previous year? What sales manager will tell us, except in the most general terms, how much additional sales and profit will be earned over what period of time as a result, let us say , of changing the size of his sales force, or the frequency of their calls on the trade? What marketing manager will actually predict the sales and profit results of even a substantial change in the total amount of money spent in the marketing effort? Or of a change in the allocation of a fixed amount of money as between advertising, sales promotion and selling?

We are told that we must have faith in these matters. I am sure that there is truth in such a point of view, but I do not honestly know how much. To quote what Simmias said to Socrates:

> "I feel myself (and I dare say you have the same feeling) how hard or rather impossible is the attainment of any certainty about questions such as these in the present life. And yet I should deem him a coward who did not prove what is said about them to the uttermost, or whose heart failed him before he had examined them on every side. For he should persevere until he has achieved one of two things: either he should discover, or be taught the truth about them, or, if this be impossible, I would have him take the best and most irrefragable of human theories, and let this be the raft upon which he sails through life. . ."

At any event, I am quite sure that if we have little to rely on except faith, then we had better hope that our judgement is awfully good, and at the same time build a very substantial reserve for contingencies into our operating budgets.

We are also told that marketing is an art, not a science. On that point, I should like to call Webster to my rescue and give you the following quotation with a bit of paraphrasing thrown in:

> Marketing management, here called an art, is sometimes defined as a science. Both designations are true. . . Science is systematized knowledge; if then the laws and principles of marketing management are exhibited in an ordered and interrelated system, they appear in the character

> of a science. Art is knowledge made efficient by skill; if then the laws and principles of marketing management are applied in the actual conduct of a marketing business, they become the working rules of an art.

So marketing then can be called an art that ideally rests on a science, on general laws and classified knowledge developed through observation and experiment.

What I am driving at is this: As marketing managers, in the aggregate we are daily making decisions involving the expenditure of literally hundreds of millions of dollars on an annual basis. Our decisions involve judgments as to the most effective out of many alternative ways of creating maximum consumer acceptance or preference for our products and presumably therefore maximum sales and profits for our companies. And yet, in my opinion, our knowledge as to the underlying structure of how people act and react as purchasers of goods and services in the market place is very limited indeed, and our knowledge therefore as to how best to affect people favorably in that purchasing environment is equally slim.

If this is indeed the case, then the situation is one that cries aloud for the application of the scientific method -- for observation, for the development of formal hypotheses, for controlled experiment -- for what Bridgman in "Reflections of A Physicist" called with perhaps a somewhat different emphasis, "doing one's damnedest with one's mind, no holds barred."

The intuitive marketing man needs the development of a marketing science on which his art can more surely and more confidently rest. This is not a plea for the substitution of numbers for judgment, of mathematical models for intuition in marketing. It is, however, a plea for us to do our best to find out thoughtfully and deliberately what the underlying structure is, to separate significant facts from mere data, to systematize our knowledge, and to let that knowledge be the basis on which seasoned judgment and good intuition can best operate.

Now let me be specific as to the things I think we can do, usefully and practically, to this end:

1. I think we as businessmen can sponsor basic research at the graduate school level in the universities to learn more about the facts of life in the market place.
2. I think we can encourage the market researchers and the media men to better understanding and more widespread use of the mathematical tools usually associated with the term "operations research," to help them gain better and more actionable insights out ofthe significant data they put together.

3. I think we can encourage the marketing man to an intensified search for and use of significant facts as the basis for his judgments.

4. I think we can stimulate observation, experimentation and analysis to help determine, bit by bit, the relative sales effectiveness and profitability of one course of marketing action as opposed to another, and of each major element in a marketing program as compared with the other major components.

   Two methods could be used in this connection, either separately or jointly: the first would be a program of planned controlled experimentation in the market place; the second would involve building tests into the established framework of the marketing operation as a regular and continuing part of it. Parenthetically, this would imply a much more rigorous and a regular attempt to appraise the sales and profit results of marketing expenditures after the fact than is, I believe, generally the case.

The fifth and last point I should like to make in this short series involves all the previous ones and depends on a particular view of operations research. I do not pretend to be an expert in that field, but it appears to me that one distinguishing characteristic of operations research, as I understand it, is the interdisciplinary approach. This involves the use of a mixed team of specialists, people whose training and experience has been in different fields and who are brought together precisely because their different approaches can show different aspects of the reality under study. I take it that such a team is best composed both of scientists and of other qualified members whose working experience is directly related to the problem involved.

With this view of operations research in mind, here is my fifth point:

5. I think we might properly encourage full-fledged operations research studies of the sales effectiveness and profitability of consumer advertising, especially in product lines where there are a number of well advertised, well promoted brands, widely available to the consumer and generally satisfactory in use.

   Measuring the effectiveness of advertising in such a case -- and it is quite typical -- is an extremely difficult thing to do. Knowing how much advertising to use is equally difficult. The chief executive of at least one marketing company, a very heavy user of consumer advertising, has said "I know that about half my advertising expenditure is wasted; my problem is that I don't know which half!" The very complexity of this subject, and the knowledge that a myriad of factors -- including one's own advertising -- affect consumer purchasing habits, suggest the desirability of trying to improve our understanding and our ability to make better decisions in this area by experimenting with an operations research approach.

I recognize that our progress in the direction I have just outlined will be conditioned very largely by our will to make such progress. That is one reason why I welcomed the opportunity to take part in this program today. However that may be, I am greatly encouraged by the experimental work going on at some of the universities, and in some advertising agencies and market research organizations. I believe we need much more of this kind of work. I am also very much encouraged by what I take to be the beginnings of a change in the environment within which marketing decisions are being made, the beginnings of a shift towards the use of more comprehensive business judgment and of a more scientific approach in problem definition and solution in the marketing area. I believe that the "breakthrough" may well come as a result of interdependent work in the social sciences and in marketing research, aided in a major but not exclusive way by the symbolic logic of the mathematician, the analytical skills of the mathematical statistician, and the amazing speed and capacity of electronic data processing machines.

Several of my friends and associates who have been good enough to read through the draft of this paper have commented on my failure to include specific examples of what I have been talking about. This, I think, is a very fair criticism and one which may well be strongly in your minds at this moment. In that connection, I should like to emphasize that the relative absence of published records as to the successful application of operations research methods to problem solving in marketing is in itself one major reason for my having given this talk as I have. Secondly, as a general observation, the work that is going on along these lines in a relatively few organizations is either largely experimental in nature at the present time or the organizations concerned have thus far concluded not to publish the results of their efforts.

I do not think I can bring these personal observations, applicable primarily to the marketing of consumer packaged goods, to a close in any better way than by borrowing a quotation from Abraham Lincoln that came to my attention recently via the announcement of a conference in linear programming at Princeton University. Here it is:

> "If we could first know where we are, and whither we are tending, we could then better judge what to do, and how to do it."

Thank you.

OPERATIONS RESEARCH IN THE AIRCRAFT INDUSTRY

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Operations research is an accepted and desired activity within the aircraft industry. Most of you are familiar with the way operations research developed during World War II. The application of operations research in the aircraft industry was not a straightforward continuation of this work. Rather, the way it developed was this: the aircraft industry was faced with problems which, after some study, appeared most easily solved by applying operations research techniques and methods, in addition to the standard engineering and scientific approaches. Operations research has been an established function within the aircraft industry for approximately nine years. At present, most aircraft companies have operations research organizations, either directly labelled as such, or performing this type of work.

The problems which are being solved within these operations research organizations are of great variety. Figure 1 indicates the major fields of study. You will note that industrial operations

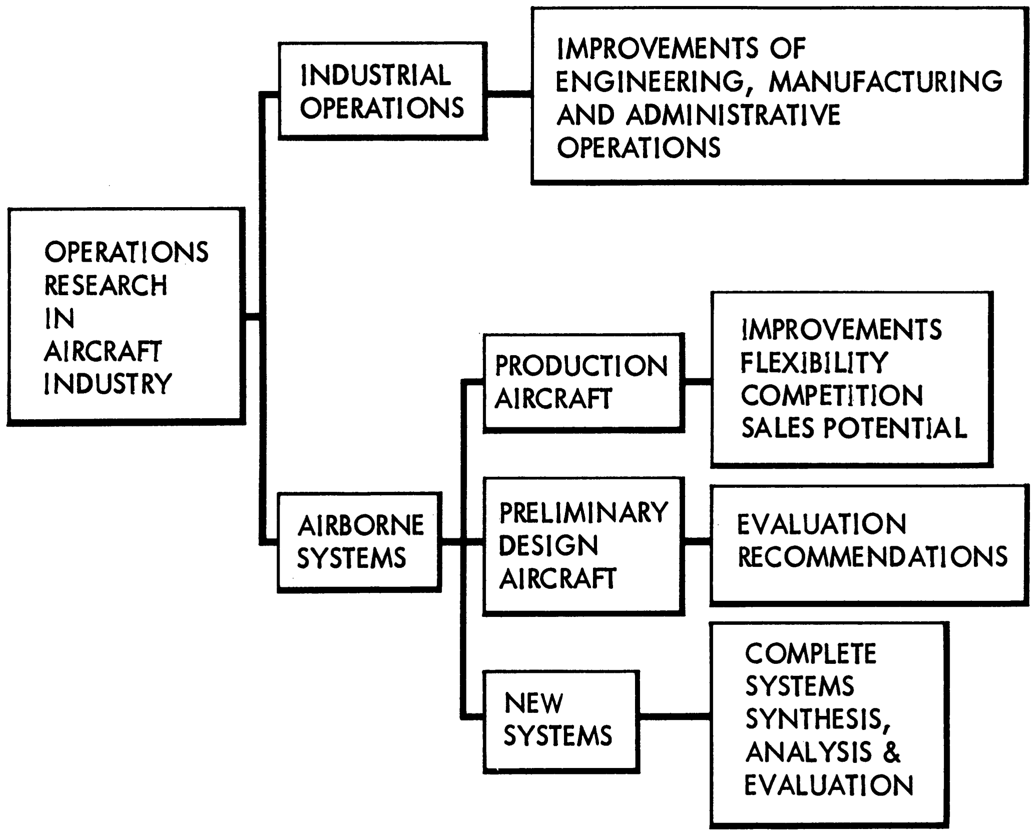


Figure 1

research is being conducted in the aircraft industry just as in many other industries. In this branch, we are primarily engaged in seeking improvements of engineering, manufacturing and administrative operations. The problems that may be considered are tool manufacture scheduling, product diversification, sales campaigns, financial operations, new plant locations, and sometimes even such simple-sounding problems as an optimum parking lot design for a new site.

The major endeavor, however, of an operations research organization in the aircraft industry concerns itself with airborne systems. The breakdowns under this activity are studies which involve production aircraft, preliminary design aircraft and finally, entirely new systems. Under production aircraft studies, investigations are made to see how an existing airplane could be improved, to determine whether this airplane could be used for other than its original mission, to investigate how this airplane compares with similar aircraft of the competition, and also to estimate the sales potential over the coming years for this aircraft. In this work, close contact must be maintained with the engineering project organization, the sales department, as well as with the user, may he be an airline or a military agency.

In the case of preliminary design aircraft studies, an operations research group will assist in evaluating a new product and will make--as a result of their evaluations--certain recommendations as to optimum operational employment of this airplane, as well as suggestions for major design changes.

Under the category of "new systems," studies are performed which investigate possible airplanes or rather airborne systems anywhere from eight to fifteen years from now. This is the most challenging and demanding area of airborne systems analysis. The need for the techniques of operations research are most apparent here. Operations research provides the most useful tools to solve complex problems, such as those posed in the analysis of airborne systems. Figure 2 provides an indication of the tremendous increase in complexity for one type of airborne mission, namely, strategic bombing. In World War II, we had the reciprocating engine, the TNT bomb and we were limited by the state-of-the-art to overseas bases. At present, we have the ability to use, in addition to the World War II capabilities, the following: Continental U. S. bases; nuclear, turboprop, turbojet, ramjet and rocket powerplants; and in the weapon field

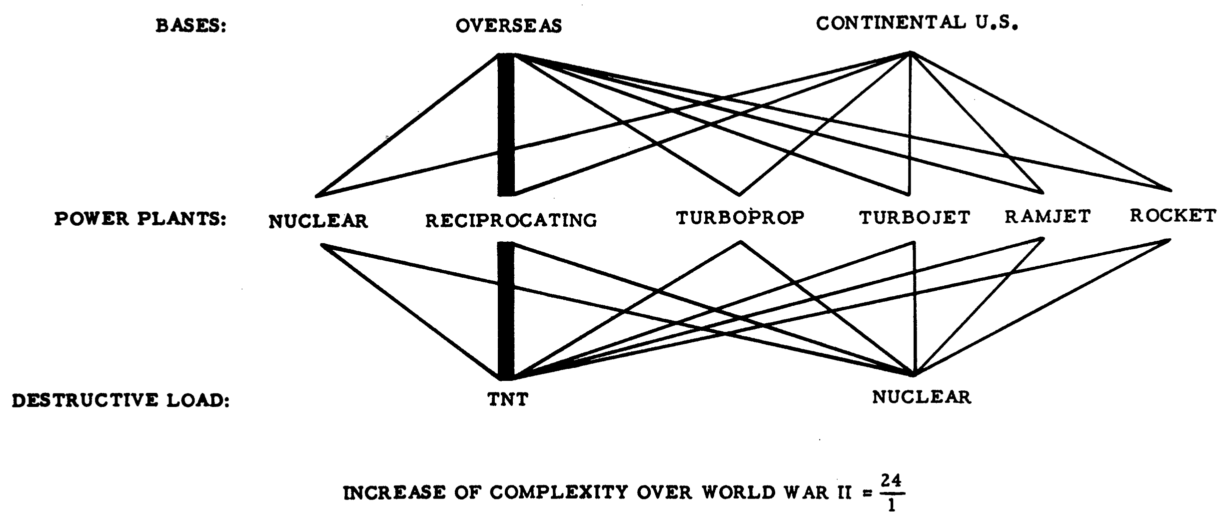


Figure 2

we have added a wide spectrum of possible nuclear bombs. The increase in complexity over World War II for this example is 24 to 1.

Once it has been established that an organization is capable of conducting these studies, then the two former types of studies on production or preliminary design aircraft can be handled without too much difficulty. Therefore, I will confine the rest of this talk primarily to studies on new systems and will discuss the problems of organizing and administrating a group which has the capability of conducting such studies.

So that we may have sufficient background for discussion of some of these problems, it is advisable to examine a greatly simplified sample problem concerning an airborne systems analysis.

The example we shall now investigate is this: Consider a military operation that requires the continuing delivery of weapons of a given type to certain enemy targets. The measure of effectiveness we decide to use is "the damage we can do to the enemy for a given budget." We select, as the best, that system which, for a given budget, causes the most damage to the enemy. Most measures of effectiveness in military systems analysis are of similar form; that is, an analytical expression is developed which determines results achieved for a given effort. Effort can usually be expressed most conveniently as cost.

To begin, for the example at hand, we consult a map and locate the targets of interest, as well as the air bases from which we expect to operate. We can now plot the target distribution as a function of the distances from the air bases, as shown at the top of Figure 3. It is indicated, for instance, that in this arbitrary example,

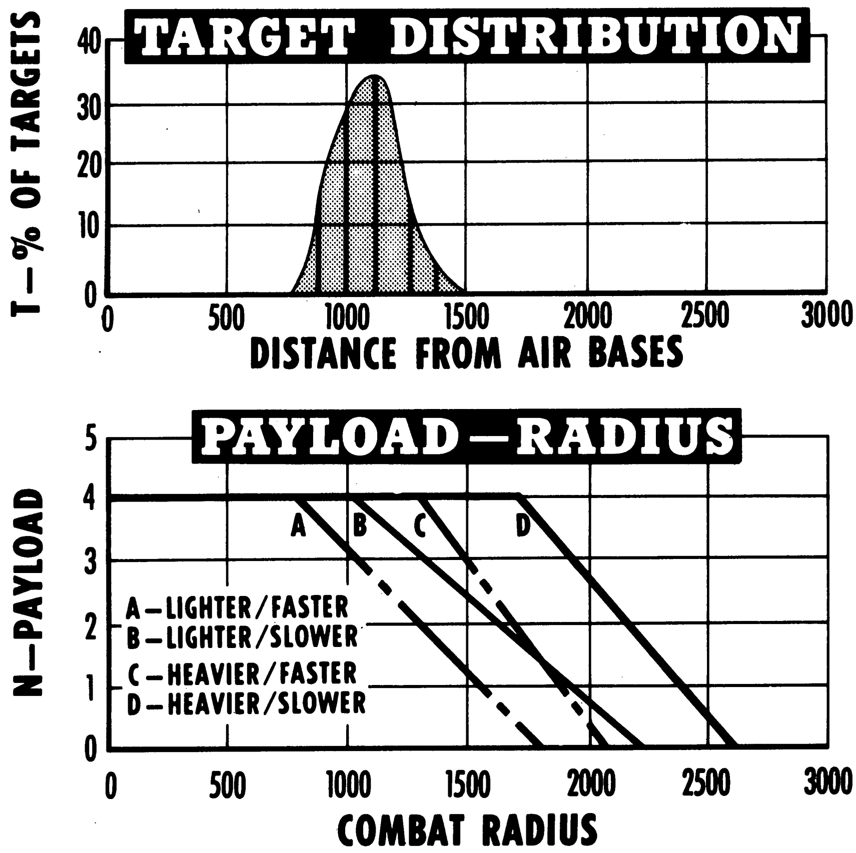


Figure 3

30% of the targets are located 1000 miles, and 15% of the targets 1250 miles from air bases. To accomplish our mission, we can choose from a wide spectrum of possible aircraft. For illustrative purposes, let us simplify the problem and determine the best airplane from four arbitrarily selected vehicles. They are all different from each other in speed and range, but for this example we assume that all airplanes have the same payload space limit.

The four airplanes under consideration have the payload-combat-radius characteristics shown at the bottom of Figure 3. It is assumed that airplanes A and B have one common take-off weight, labelled "lighter"; and airplanes C and D have another common take-off weight, labelled "heavier." Furthermore, it is assumed that airplanes A and C have identical speeds, labelled "faster," and B and D have identical speeds, labelled "slower." A reasonable simplification for this illustrative problem is to consider the cost of the entire operation proportional to airplane take-off weights (see Figure 4).

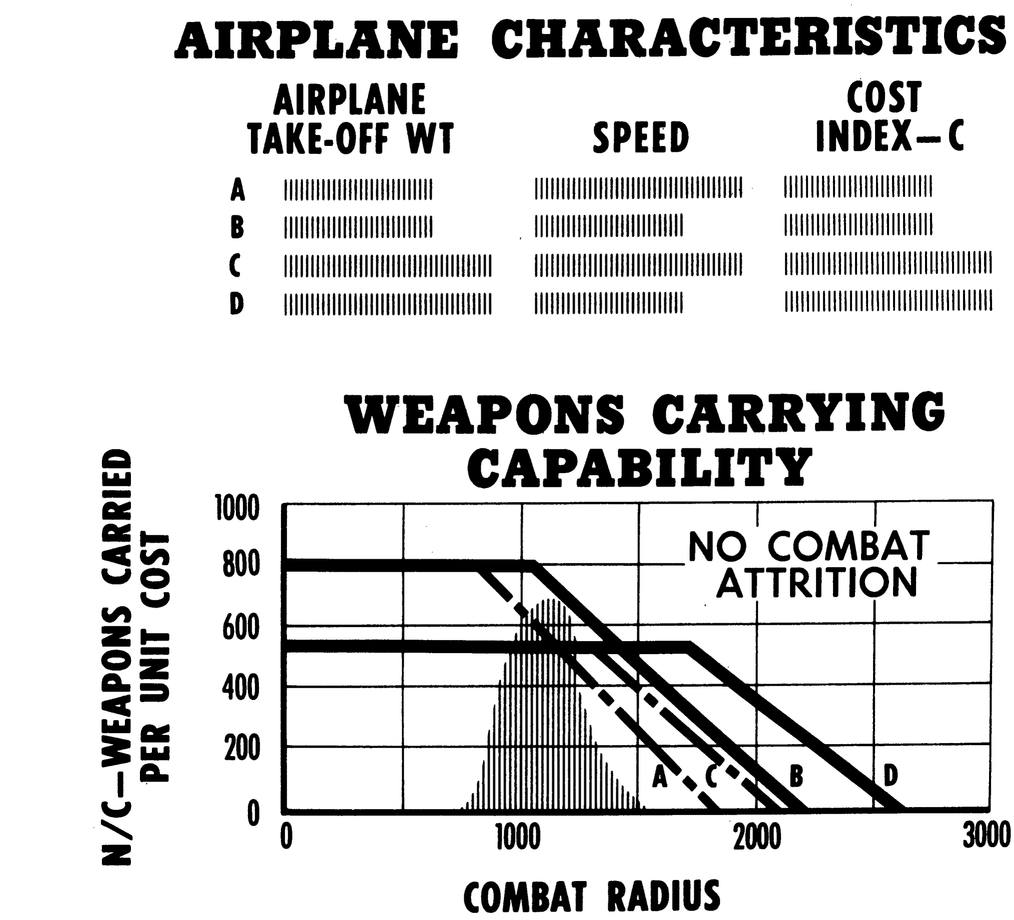


Figure 4

Let us examine the load-carrying abilities of these four airplanes on the basis of their range, payload and cost characteristics, but ignore for the moment target distribution and combat attrition. The lower diagram of Figure 4 shows the number of weapons carried per unit cost as a function of combat radius. It is indicated, for instance, that attacking forces equipped with airplane C can carry 400 weapons per unit cost to a target located 1500 miles from air bases.

It is now necessary to combine these load-carrying abilities with the geographic requirements, i.e., the target distribution, T, as a function of distances from air bases. This is achieved by summing the products of T x (N/C). The target distribution factor, T, is essentially a weighting factor for the weapons carried per unit cost. The larger T is for a certain distance, the more important it is to have a high (N/C) for this same distance. The curves resulting from these products, T x (N/C), are shown in Figure 5. Also given in this

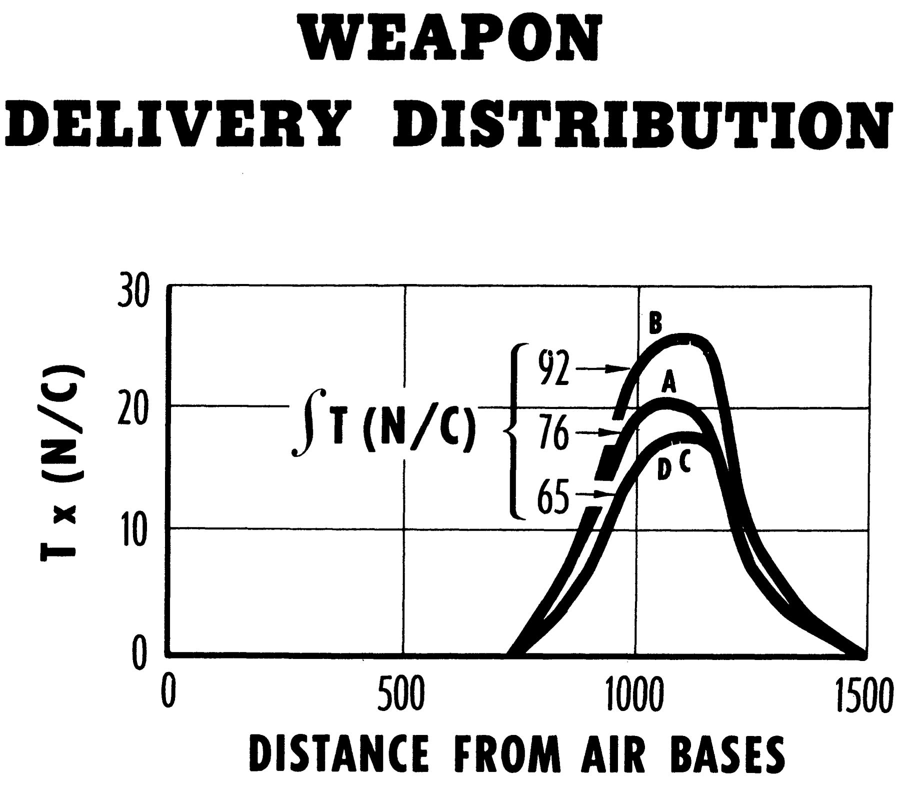


Figure 5

figure are the integrations of these curves. Airplane B is better than airplane A by approximately 20%, and better than airplanes C and D by approximately 40%.

Let us now suppose that combat attrition decreases with increase in airplane speed. Figure 6 indicates a representative relationship of the probability of the airplane's being shot down as a function of speed. Shown also is the average number of combat sorties an airplane can fly. The latter is the reciprocal of the kill probability. For the problem at hand, we assume that the faster speed airplanes (A and C) have a probability of being shot down of 5% per sortie; for slower airplanes (B and D), 8% per sortie. This means that the faster airplanes will fly an average of 20 sorties and the slower airplanes an average of 12.5 sorties during their combat life. The airplane costs must then be amortized over these respective lives. Stating it differently, the integrations of T x (N/C) must be divided by the respective kill probabilities. These results are shown as the set of bars at the right of Figure 7. The relative standings of the airplanes are indicated by the set of bars on the left side of this figure where no combat attrition is included. The right-hand set includes combat

AVERAGE NUMBER OF SORTIES

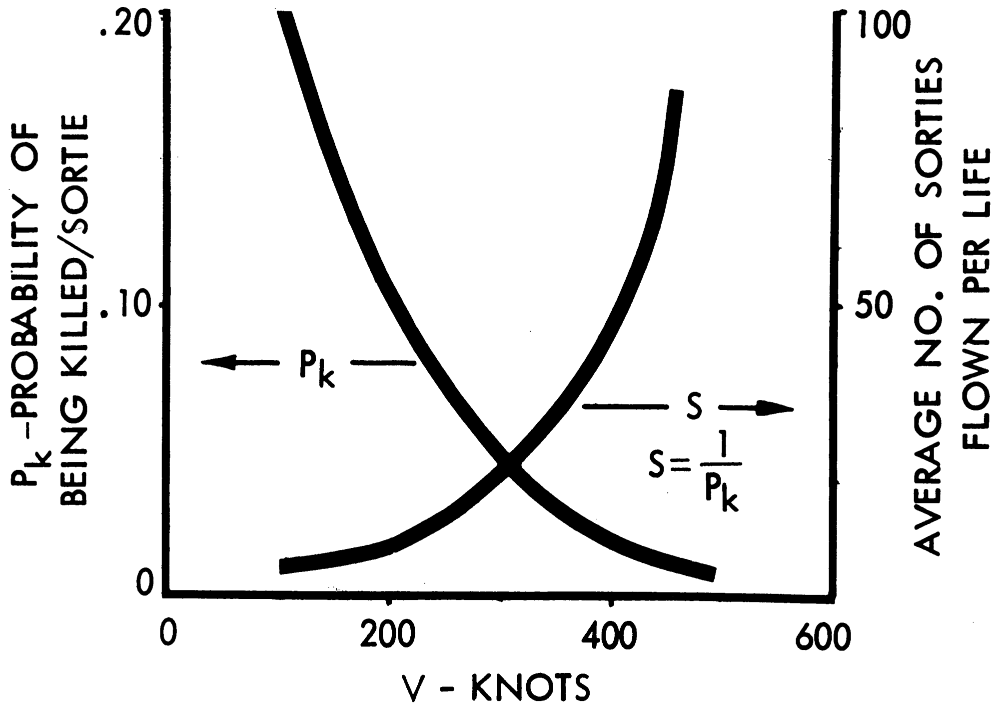
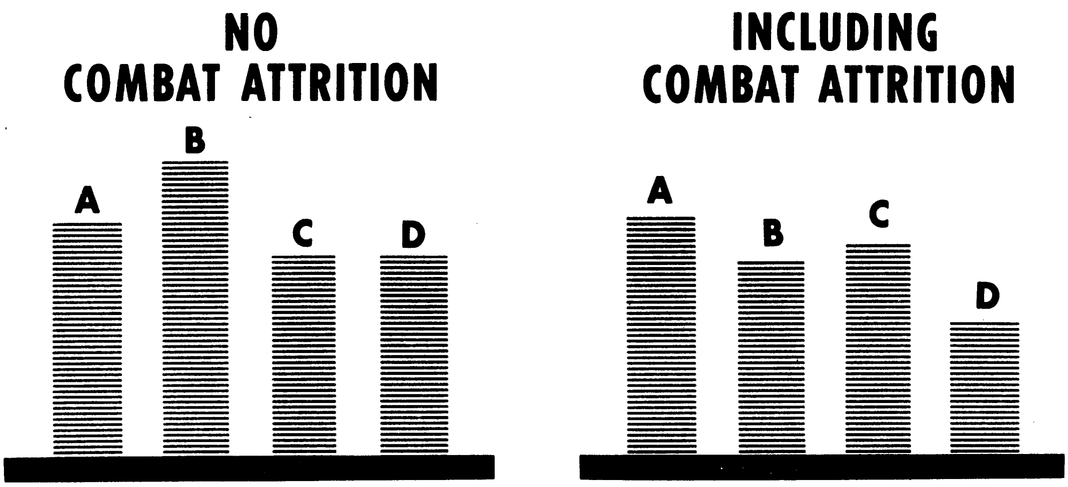


Figure 6

WEAPONS DELIVERED
PER
UNIT COST



(FOR ASSUMED TARGET DISTRIBUTION)

Figure 7

attrition and it is shown here that airplane A is the best of the four airplanes on the basis of weapons delivered per unit cost, target distribution and combat attrition.

This example has been quite limited. Only a few of the parameters which enter into a systems analysis have been included. In a full-blown systems analysis, we must consider many additional parameters; e.g., different types of powerplants, altitudes of operations, various sizes of maximum payloads, non-combat attrition of airplanes, airplane sortie rates, weapons destructiveness and hit probabilities, airplane abort probabilities, enemy defense effort, effect of enemy attacks on our own bases, base costs, various other base locations and numerous other factors. All these parameters must be combined into one analytical expression, and reliable quantitative data must be obtained for each.

In order to demonstrate the effect of making a wrong decision, R. A. Bailey, in a paper published in Operations Research Society of America (Vol. 1, No. 4, August 1953), presented an interesting table. The system analyzed there is different from the one just discussed; however, a similar table could be constructed for any system studied.

	OPTIMAL SYSTEM	A	B	C	D
CRUISE SPEED (N. MI. HR.)	235	300	235	235	300
COMBAT RANGE (N. MI.)	2600	2600	3500	2600	3500
MILITARY LOAD (LBS.)	19,500	19,500	19,500	11,000	11,000
EFFICIENCY	1.00	.43	.77	.50	.11
GROSS WEIGHT (LBS) (APPROX.)	88,000	260,000	140,000	56,000	360,000

Figure 8

"Figure 8 shows a typical example of the penalties for errors in planning decisions for a new airborne weapon system. Take the efficiency of the optimal system as 1.00. Then if, as in system A, the planner were to demand too high a cruise speed by only 65 knots, he would reduce the system efficiency to 0.43. In system B he has reduced the efficiency to 0.77 by demanding too large a combat radius; in system C he has reduced the efficiency to 0.50 by selection of too low a military load. If we were to miss all three parameters, as shown in system D, an extremely inferior and costly weapon system would result.

Since efficiency is not only a measure of cost but also one of capability against the enemy, the value to the planner of the knowledge of such results before the airplane system is ever designed becomes obvious.

Although the value of such analyses is great, the cost is relatively small. Experience to date has shown that a typical systems analysis may be performed for a cost on the order of 2 to 10 percent of the cost of a single airplane. This appears to be a small premium to assure that we are getting the most power for the least dollars when creating a new airborne weapon system to meet the enemy on equal or superior terms."

The examples just discussed are actually quite narrow. In order to fulfill the objective of looking at the problem in "its entirety" (the theme of the operations research approach) and to be of additional help to the defense establishments and to our own companies we should ask ourselves questions such as the following, and seek to find answers: If the preceding example, say, determined the best airborne system to accomplish bombing of industrial targets, then (1), is there another and better way to accomplish this mission, or (2), is the destruction of enemy industry a deciding factor, or should we concentrate on entirely different missions to win the war? These considerations are important to the military as well as to industry. If an airplane manufacturer is conscientious about his job, he should not only endeavor to design an airplane with the best characteristics for a given mission, but he should also ascertain whether the mission for which he is planning an airplane is of importance to the nation in a future war, whether it be peripheral or all-out nuclear.

In order to do these studies successfully, they must be conducted by an operations research group which is located properly within the organization of the company; is directed by the right management; has the right relationship with the military agencies; is staffed with the right personnel; and is operated on a business-like basis. Most of these factors just mentioned are related. However, an attempt will be made to discuss them separately in the order just mentioned.

It should be stated that some of the following remarks are personal opinions and do not necessarily reflect the opinions throughout the aircraft industry.

First, the location of operations research within the company: It has been found desirable that operations research groups should be located within the engineering department. The engineering department is the creative part of an aircraft company and operations research fits most logically into this organization. As far as location on the organizational chart is concerned, the person to whom the organization should report is not too important. What is very important is that this group report in such a manner that channels of communication are open to top management. Its position in the organization set-up should be such as to give it prestige enough to invite the cooperation of other organizations within the company. An operations research group cannot work in a vacuum. It requires ready information from many sources. Furthermore, since it will frequently contact and collaborate with important military agencies, it should also be located organizationally so that an outsider realizes that the company considers operations research an essential part of the company's activities.

Second, problems facing the manager of an operations research group: Managing an operations research group poses many problems. (1) The manager of such a group should be a technically capable man. Although engineering itself is dynamic and an ever-progressing field, there is a considerably greater need for continuous training of the personnel in operations research work. This can only be administrated and achieved if the top man of an OR group has a reasonably sound technical knowledge himself. (2) This manager should be able to induce specialists in their respective fields to become interested in related subjects and in the overall problem under consideration. (3) He must be able to dispel some of the anxieties that good engineers and scientists in this type of work will have about not achieving the precise results achieved in their past specialized studies. A design engineer will have the satisfaction, normally, of seeing in hardware form the fruits of his endeavor. In operations research, the results of many man-hours of work are sometimes summarized on an unimpressive-looking piece of paper. Probably one of the most difficult aspects of this type of work is that feedback cannot be achieved in a short time. In most engineering work, one usually knows within six months to one year whether predictions and calculations were correct. In new systems analysis this satisfaction can hardly ever be achieved. (4) The operations research manager must be able to convince the scientist that within industry it is necessary to adjust to the rules and regulations that must govern industry. He must make the researcher realize that applied research must be scheduled so that decisions can be made at the right time, and that studies can be made,within realistic budgets. (5) The manager should also let his researchers make mistakes, even though he might have known at the outset that this could occur. He should remember from his own experience that the only way to learn is to have struggled through a problem oneself. On the other hand, he must be an annoying stickler for details in report preparation. He must insist that his men make excellent presentations to top company and military officials. (6) He must be able to make his researchers understand that his company, as a part of American industry, is primarily in business in order to make a profit, and that applied research must be directed toward that goal.

Third, relations with the military organizations: Contact with the military organizations will be, primarily, with the research and planning branches. The military planner is one of the most harassed individuals of our society. As a rule, he needs and welcomes the help of industry. We feel that the aeronautical industry should participate in this fundamental planning. Modern weapons demand a combination of technical "state-of-the-art," national policy, operational feasibility, and knowledge of future technical possibilities. None of these can be successful without a reasonably accurate scientific consideration of all the others.

It is essential that operations research in industry dispel the possible suspicion by the military that it is a part of the company's sales effort. Sales Departments concentrate primarily on selling current and near immediate products. In doing this, a good salesman will stress the good points of his products and be quiet about the less desirable ones. Operations research cannot operate like this. This does not mean that operations research is more virtuous than selling. It simply means that operations research has a different charter. In all OR studies, the greatest objectivity must be maintained. Only by being objective can it be of assistance to the company, the military and to the country. In the course of their studies, weapon systems researchers are acutely aware that they are dealing at times with systems which eventually may involve millions or billions of dollars of expenditures.

On a new systems study, the best possible procedure appears to be as follows: After the broad assignment for the study has been given by the military research agency, the researcher should take a month or more to formulate the statement of the problem in as detailed a way as possible, devise a measure of effectiveness, establish the important assumptions and examine the accuracies of the required input data. If at all possible, it is highly desirable to work through a "pilot" analysis. There is nothing else so helpful for coming to grips as early as possible with the total problem. Such a procedure will help in developing the methodology and point out possible weaknesses. This initial study should be reported to the cognizant military agency in order to benefit from their thoughts and experiences as well as receive their comments on the measure of effectiveness and the major assumptions. This is an important conference because the decisions reached at this stage will essentially dictate the final results.

During the course of the study, close liaison will be maintained with the contracting agency. In addition, study members should contact the operating commands. The researcher should not be too surprised to find that in these organizations, interest shown in future weapons is not as active as he would expect. This is definitely not a criticism of our operating commands. Rather, it stresses the fact that these people are extremely busy running their everyday operations. However, the researcher will benefit a great deal by exploiting these contacts and by participating in regular military exercises. It will give him a feeling for the many non-quantifiable factors which must be considered in a weapons system analysis.

After completion of the study, presentations will, of course, be made to the contracting agency and other interested organizations. This phase must be attacked vigorously and with great enthusiasm. The researcher must realize that the old "mouse trap" adage is fallacious. He should know that in order to be successful, he must be able to explain his results to top level organizations. If he simply believes that his report should be filed with the many others, he has not done his job. A great amount of money has been invested in his work and the pay-off or justification for this expenditure comes only when people who make the decisions understand what he has done. If this is not so, he might just as well have never made the study.

Fourth, the problem of selecting the right research personnel: The sample problem discussed in this paper has indicated the many fields of engineering and science which are necessary for the solution of weapon system problems. It is essential that such studies be made by groups composed of personnel with outstanding professional knowledge and with the right temperament. The ideal airborne systems researcher has good analytical ability, is an expert in at least one pertinent field, is confident about his abilities, can adapt himself easily to new assignments, has interest in the overall problem, has a feeling of strong responsibility for his work, and can collaborate well as a member of a study team. It is not easy to find people with this combination and it is not easy to evaluate a researcher on all these factors in a short time. A study group should, therefore, be selected carefully and slowly.

There are two schools of thought on how to obtain the best men for operations research. One says that operations research courses should be taken in college and that the student, after obtaining his degree, will step directly into operations research work. The other contends that operations research workers should be drawn out of other scientific fields and be trained for operations research. Both approaches have a certain merit. I prefer the latter for operations research on weapon system analysis. One reason is that men with thorough technical knowledge about certain fields, such as aerodynamics, powerplants, electronics, meteorology, and nuclear physics, are required for these studies, and another reason is that the researcher will have the opportunity to stay abreast of the improvements in the state-of-the-art through his continuing acquaintance with men who stayed in the specialized fields or through his association with the respective professional societies. Furthermore, this researcher will usually have worked, in his pre-weapon system assignments, on problems which, within a few months, provided him with a check as to whether he did a good job. This has trained him to be aware of the responsibilities of his signature on a piece of work and gives him confidence in his scientific abilities.

The four items just discussed--organizational status, managing of the study groups, relations with the military, and staffing the organization--are probably the most important ones of concern to operations research in the aircraft industry. Although great strides have been made in the application of operations research to airborne-systems problems, and useful results have been achieved, the contributions which will be made in the future will be even more noticeable. Some good-natured arguing is occasionally indulged in to define "operations research." My own definition is that operations research is an orderly and objective approach to the solution of complex problems in as wide a scope as possible. There is nothing new about the desire to do this; what is new is that we are doing it!

UNIVERSITY-INDUSTRY COOPERATION IN OPERATIONS RESEARCH

Robert H. Roy
Dean, School of Engineering
Johns Hopkins University

Thank you, Professor Thrall, Ladies and Gentlemen:

I was a little disappointed by the very last thing that Professor Thrall said because I was intending to begin, and indeed shall, by remarking that each speaker throughout the day has succeeded in finishing his talk right on the button. As a matter of fact, I think Mr. Selwood concluded his last work and put a period beside it precisely when the sun crossed the zenith. Observing this, I've become convinced (in fact, I feel a little bit now as if I had a stop watch on me) that the speakers have been put on some sort of a task and bonus system. The only regret I have is that Mr. Buschmann ran about five minutes over -- and he gets only base pay.

I also have some notes from which I was going to say something about Operations Research, not as a definition -- I hope I've learned better than that -- but by way of a few introductory remarks about the nature of Operations Research as distinct from Industrial Engineering. I will not attempt a definition other than the one given by example several years ago in our seminar by Dr. Solandt, who is the head of OR in the Canadian Defense Establishment. He too had suffered from a plethora of OR definitions, and had decided upon a form of rebuttal by means of an anecdote. I like the anecdote except for one thing. It has an anti-climax as you shall see, but I think nonetheless it's a good anecdote. At the risk of dredging up a distant past, it goes something like this.

A young student heard about OR and became very zealous on the subject, very anxious to get into OR, and he went in to see a professor of mathematics who was active in the field and made his wishes known to him. The professor of mathematics was very cold and negative about it and insisted that the student did not have sufficient sophistication to participate in OR. The young man persisted and persisted and persisted, and finally he said, "All right, I'll test you, I'll give you a problem". The young man said, "All right". The professor said, "Son, here's the problem. Two men climb a chimney to clean it and they come down, one has a clean face and one has a dirty face. Now which one will wash his face?" Without any hesitation, the young man said, "Why, the man with the dirty face". "I'm sorry, son, you haven't got the touch". "Well, what's wrong with that?" He said, "Well, the two men would come down, the one with the clean face and the one with the dirty face. The man with the dirty face would look at the man with the clean face and see that it was clean and assume that his own was clean. The man with the clean face would look at the man with the dirty face and assume that his own face was dirty also and he'd go off and wash his face."

Well, the young man was considerably chopped down about this and after some pleading, the professor said, all right, he'd give him another chance. Here's another problem, "Two men went up a chimney to clean it and when they came down one had a clean face and one had a dirty face. Which one would wash his face?" The young man was astounded by the repetition, but said without any hesitation, "Why, the man with the clean face." The professor said, "I'm sorry, son you haven't got the touch." "Well, sir, I don't understand." The professor said, "That isn't what would happen at all. The man with the dirty face would look at the man with the clean face and see that his face was clean, assume that his also was clean and he wouldn't do anything. The man with the clean face would look at the man with the dirty face, assume that his own face also was dirty and he'd start to go off. The man with the dirty face would say, 'Hey, where are you going?' 'I'm going to wash my face.' 'What for?' 'It's dirty'. 'No, it's not.' 'Your's is', and the man with the dirty face would wash his".

The young man again remonstrated successfully, and as you've guessed, the professor gave him the same problem, and here I think is where the story lets you down rather badly. The student answered that the man with the dirty face would wash his face. The professor said, "I'm sorry you haven't got the touch." The student demanded to know what was the matter this time. "Well, you should have said that the problem was not a valid one in the first place." And so, I will not attempt to define OR in other than in this facetious manner.

I will say a couple of things about it, however, because I can pick up one thread left by Mr. Buschmann. Since I do come from an institution where there is a program of graduate training in this field, I can most heartily agree with his belief that a person working in OR should have depth in some traditional discipline. I think if that day ever arrives when all of our OR teams consist of people who have been trained in linear programming, operation gaining, monte carlo etc. etc., then we shall have lost a vital ingredient of OR, namely, the mixed team concept. I will return to this theme later in stating one of the advantages that I think a University can have for industry in the general field of Operations Research.

In discussing the general question of how a University may be of value to industry, or to government, or to other forms of organizations with respect to OR, I would like to first discuss this facility with respect to large organizations. I am very conscious of the fact that in large organizations it is possible to have a sufficiently large group performing work of this kind to have what I have heard described as "viable teams". I am also aware of the fact that in large organizations it is possible to have different disciplines represented in such a way that the team can be a genuine mixed one On the other hand, I always suspect that this is apt not to be so.

I can support this with a rather trivial example which I hope will make just one small point. A year or so ago, when he was president of the Operations Research Society of America, I heard Roy Brothers describe a piece of work done by one of his OR analysis group teams with the Air Force. He stated that at some western base it had become imperatively necessary to devise some form of job evaluation for some sort of job, I don't remember what it was. His group was asked to undertake this, it was politically impossible for them to turn it down, and he assigned to the task of establishing a job evaluation system, a team consisting of something like -- this is not necessarily accurate -- a geophysicist, a thermodynamicist, and a statistician. I don't know the response this invokes in you, but it gives me the horrors. I think that to assign someone to the analysis of operations, rather than to their performance or to rendering service is organizationally quite sound, and I would be prepared to agree that to assign three such persons to a problem like this is better than no assignment at all. At least the potential is better. On the other hand, I think this is entirely contrary to the appropriate spirit in which OR problems should be attacked. There would be in any job evaluation problems of psychology, sociology, economics, labor relations in which the kinds of persons described could hardly be competent.

I argue, therefore, that it is an essential ingredient of OR that the mixed team be appropriately chosen for the task at hand. I am a little fearful that, even in larger organizations with their flexibility in this regard, there will be many cases in which the assignment will be made to teams of persons who come from disciplines inappropriate to the task at hand. I think it is fairly obvious that I am going to say that a university, either by contract research or by consulting facilities, can help to supply some of the gaps by the wealth of the disciplines which are represented on a university campus. This I think, can be, and often is, an important contribution to OR in larger organizations.

In terms of small organizations, the potential value of the university is much greater. There are many establishments to whom the cost, relative to other costs, of an OR team would be prohibitive, even if the small organization in these cases could attract the kind of mixed team which would be suitable for its particular problems. There would also be a lack of flexibility which would inhibit the formation of OR groups by small organizations. And then I think one comes to another very important character of many small organizations which permits of the kind of OR which I am going to describe and exemplify at somewhat greater length.

For example, the industry in which I used to work, commercial and publication printing, is sufficiently homogenous throughout the country, in its manufacturing requirements, its markets, its technology, its manpower, labor problems, and yet is composed of organizations too small to engage in this kind of work independently. The only way such an industry can have OR is by approaching it cooperatively, and the university can afford an appropriate mechanism for this. Other examples of industries that are relatively homogeneous in their manufacturing, marketing, and manpower problems are the textile industry, the newspaper industry, of which I shall speak in some detail, jobbing machine shops, banks, merchandising establishments, and the like. No doubt, there are many others. I could say something about railroads here, they certainly are homogeneous enough, and there has been some disposition to attack their problems by means of OR, but apparently results so far have not been too successful.

Having said that universities could be valuable to small organizations on a cooperative research basis, I want to examine a case in point. First I would like to narrate an initial disappointment of my own. I mentioned that I worked for a number of years in the printing industry. The first proposal that I ever made of this kind, indeed before I had ever heard of OR, was for a cooperative research attack on problems in the commercial printing industry. This got to the point of preparing a research proposal, budget, staff, and all the rest of it, which then never got off the ground, chiefly because the association responsible for it had at its head a man who thought the first step should be to ask the foremen of the industry what research they thought was appropriate. This, in effect, was the kiss of death and the program never got started. More fortunately, and more recently, a group of us at Johns Hopkins have been engaged cooperatively in making studies in the newspaper industry. I should like to exemplify university-industry cooperation in this field by a case study which I will describe as briefly as I can.

First, let me say a word about the industry, its trade association, the attitudes of some of its members, and some of the forces which are currently at work because of the state of the industry. The newspaper industry is marked for the most part by small, closely held organizations. Except perhaps for the Hearst and Scripps-Howard newspapers, and I'm not even sure about these, I think very few newspapers have securities for sale on the open market. Most newspapers are closely held. They do not publish financial statements, at least not publicly, but one can surmise that around there are a considerable number of outstanding newspapers which are very, very profitable. On the other hand, the economic trend of the industry is clear for all to see. It is not a healthy economic trend.

Within the recent past, the Boston Post has closed its doors, with an attendant loss of employment to those who formerly worked there. Just before that, the Brooklyn Daily Eagle similarly was liquidated. Not so many years ago, the Philadelphia Public Ledger disappeared, and the Philadelphia Record has fallen by the wayside. These I can name just by calling them from memory.

Another characteristic of the industry has been merger. I don't believe we have had any mergers adjacent to this area, the Detroit News and the Free Press are still substantially as they were but, in New York, the World-Telegram-Sun formerly represented three newspapers. In Washington, the Times-Post-Herald formerly represented three newspapers. I could go on by searching my memory to name other, similar mergers around the country. With the possible exception of the Chicago Sun, which had behind it Marshall Fields' capital, I do not know of the successful start of a newspaper in the U.S. for a considerable number of years.

Let me point this up by some information quoted from Fortune, September 1951 issue, which was found by one of my students: "In 1946 the hypothetical large newspaper made 15 cents net before taxes on every dollar of revenue. In 1950, if it had shared the experience of the over 100 thousand circulation-group, it would take in about $1.68 for every 1946 dollar, but would make only 6 1/2 cents instead of 15." Then the article goes on to say that at this rate the breakeven point was about two years ahead. Why the newspapers are now not all out of business to agree with the prediction I don't know. This will give you some idea of the current trend in the industry. Marginal papers in highly competitive areas such as Boston are suffering. This is also true of the smaller newspapers. They're suffering from highcosts and they're suffering from competing media too.

As a consequence of this a few years ago a group within the American Newspaper Publishers Association proposed the formation of an Institute of Newspaper Operations. Initially, they proposed that the newspapers band together for the study of their operations, but the governing groups within ANPA were not ready for the idea. They were still intensively preoccupied with hardware research in a laboratory in eastern Pennsylvania which they still support. The group interested in a study of operations, and believing that this was essential to the economic health of the industry, set up a separate organization, which they called The Institute of Newspaper Operations. It was this group which approached us in the spring of 1955.

A contractual arrangement was entered into between them and ourselves, and that summer a group of us began a survey of newspapers along the east coast and as far west as South Bend, Indiana, and Chicago. I might add, apropos of a remark made by Dr. Schulz this morning, that a member of the initial survey team was the long-time president of the International Typographers Union local at the Louisville Courier-Journal. He was loaned to us for this purpose by the Courier-Journal, which paid his salary and expenses. Although he was in no sense a technical man, his value to us in that initial approach to unionized shops cannot be overstated. I think in a number of instances we could not even have gotten in, had we not had this satisfactory identification with a representative of the union. He, incidentally, was a very, very good man.

By the time that this survey began, we had had some discussions about what we were going to study. Here again one gets into the questions of optimization of whole systems, sub-optimization, over-optimization, and under-optimization. After much discussion, we decided that we would study the composition of local display advertising. This decision carried with it the flavor of many things. Some of the flavor was political. This is an industry in which the union relationships, particularly in the composing room, are extremely sensitive. The union itself was known to be interested in newly developing methods of composition, and it was believed therefore that a study undertaken by the Institute and under the Institute's sponsorship could be done without invoking the hostility of the union. This indeed proved to be the case.

Other reasons for studying local display advertising, however, lay simply in the fact that this is the largest single source of newspaper revenue and the largest single source of newspaper expense. I am well aware of the fact that newsprint has almost skyrocketed beyond imagination as an element of cost, but you must use newsprint to print local display advertising too. It is therefore a part of the cost of LDA and LDA does constitute a plurality of revenue and a plurality of expense in any newspaper with which I have had any contact; it is in some almost a majority.

Yet another reason for choosing this particular product is that there are emerging methods of photographic composition and the long-range objective, which was stated, was that we would make an economic comparison of the currently used hot metal process, Linotype and Intertype, with these emerging methods of photographic composition. That still remains our long-range objective, but we haven't even begun to approach it, because we've turned up so much in other ways.

After this survey which I have quickly described had been completed, we began to consider ways and means of studying this particular operation. It is a very complicated one and, if I had time to spend on process charts and the like, you could get some idea of its complications.

Before I described that, though, I neglected to mention one thing. As non-newspaper people, fresh to the industry, during the survey of 1955 we were all struck with great force by the range of what we subsequently came to describe as free services rendered by the newspapers throughout the country. I am misnaming these, they are not free, they are buried in the rates by which advertising is sold, but they are not distinct; no charge is made in any distinctive way between an advertiser who utilizes these services and one who does not. To touch quickly upon these, most of the metropolitan dailies give what are called unlimited store corrections. It is not at all uncommon for an advertiser to tear his copy apart to such an extent that the newspaper simply starts over again, throwing the original type in the melting pot. Unlimited free photoengraving was characteristic of other newspapers that we saw and so were unlimited tear sheets and unlimited proofs. In one newspaper we found a staff totalling 26 artists and commercial photographers, who draw and photograph merchandise for their advertisers, without any differential charges in the advertising rate. As I say, we were very much struck by this.

Having got through this survey, to return to that particular theme, we set about taking some measurements, and after a lot of discussion about how we might go about this, where we might do it, we finally settled upon two newspapers where the management and composition were quite favorable to the idea of being measured. A decision to utilize self-recorded data was made in recognition of the fact that utilization of the stop-watch or anything like it in this particular industry simply would not be permitted. Therefore, we asked the operators to record on their own behalf and I would like to show you the first slide to indicate how this goes.

THE JOHNS HOPKINS UNIVERSITY
INSTITUTE OF NEWSPAPER OPERATIONS

The Johns Hopkins University in cooperation with the Institute of Newspaper Operations has undertaken a project to study the composition of local display advertisements.

We are asking you to cooperate by helping to gather the information that is needed to make the comparisons.

DIRECTIONS FOR USING THE DATA SHEET

1. Each day you will find a data sheet with your time card. Keep this sheet with you and return it at the end of the day to the box near the time clock.

2. The various operations that you perform on the ad during its production are coded by number to facilitate your handling of the form.

3. Number 52 is "Delay" and should be used to show circumstances which prevent you from performing your job. When this code is used please explain the reason in the Remarks column. For example: breakdown; waiting for copy; etc.

4. You may sign your name to the data sheet if you wish but this is not required.

5. The last column will be used by us to compute the elasped time of each operation.

6. The member of our research team who is working in your composing room will answer any questions you may have about the data sheet or about the I N O project.

7. Sample data sheet

JOB NO.	OPERATION NO.	REMARKS	TIME START	TIME STOP
2057	11		8:00 AM	8:17
	52	Breakdown	8:17	8:32
1983	13		8:32	8:40
	52	Wait for copy	8:40	8:50
2034	11		8:50	9:13
2013	12		9:13	9:19
1995	14		9:19	9:24
2009	11		9:24	9:40

Fig. 1. Instructions to compositors and portion of a sample data sheet.

Slide 1

I won't dwell upon this long. We have code numbers for the operations to be performed, 11 is original Linotype composition, 52 is a delay, 13 is store corrections on the Linotype, 14 is second store corrections, and so on. You notice that we did not ask for any identification from the operators. In consulting one of the psychologists on the faculty, we were advised that we'd get better data if we left the records unidentified. We collected a vast amount of data from two newspapers over 4-week periods by this means. In fact, from one of the two newspapers, we got some 60,000 items of data. Those of you who have worked in OR would be cognizant of the fact that we are here employing data for the purpose of finding a model rather than finding a model of the process by other means. This is very much like the way industrial engineers behave of course.

The next slide will indicate a concept which finally helped us to solve this problem. After we had the mass of data, what kind of relationship could we get between what was done in the composition of an ad and the time required to do it? We were seeking a measure of time and a measure of cost, there being no standard cost accounting whatsoever in this industry. There are no means of comparing the costs incurred by various customers with the revenue received from them.

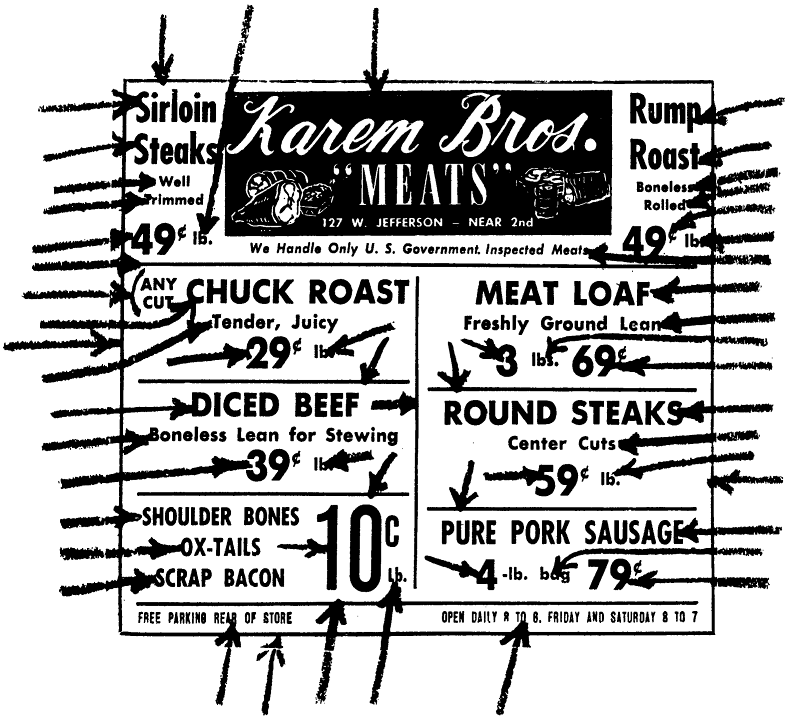


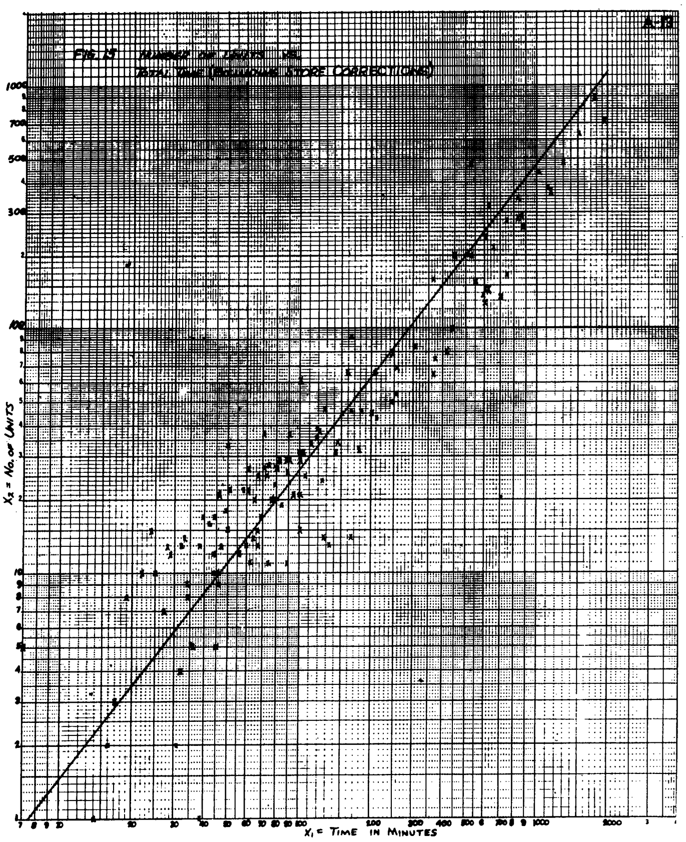
ILLUSTRATION OF ASSEMBLY UNITS

This ad contains 54 assembly units
as indicated by the arrows.

Slide 2

This, I think, illustrates the value of a mixed team, in that the notion was advanced by a former practical printer (I was that person) that the time to compose an ad might be a function of the number of assembly units that it contained. An assembly unit was defined as any single type-high element which must be handled individually by the assembly compositor. As a test of whether this relationship had any validity, we arrived at the concept and then set about counting some units. We were searching for an assembly unit-time relationship, a two-variable relationship. These arrows simply indicate the number of assembly units in that ad. If you are appalled at the idea of counting them, I assure you it is not nearly as bad as it seems.

After we had begun to do this, it was suggested we had better plot the points -- an obvious thing to do -- and, simply because the scales were of the order of magnitude that you see, we used log-log paper. We plotted a sample, randomly chosen, of about 70 ads, and from the trend that you see indicated here, it seemed reasonably clear that we were on the track of something meaningful. We chose another sample, quite independently, plotted it independently, and to our delight found that it registered quite well this time.



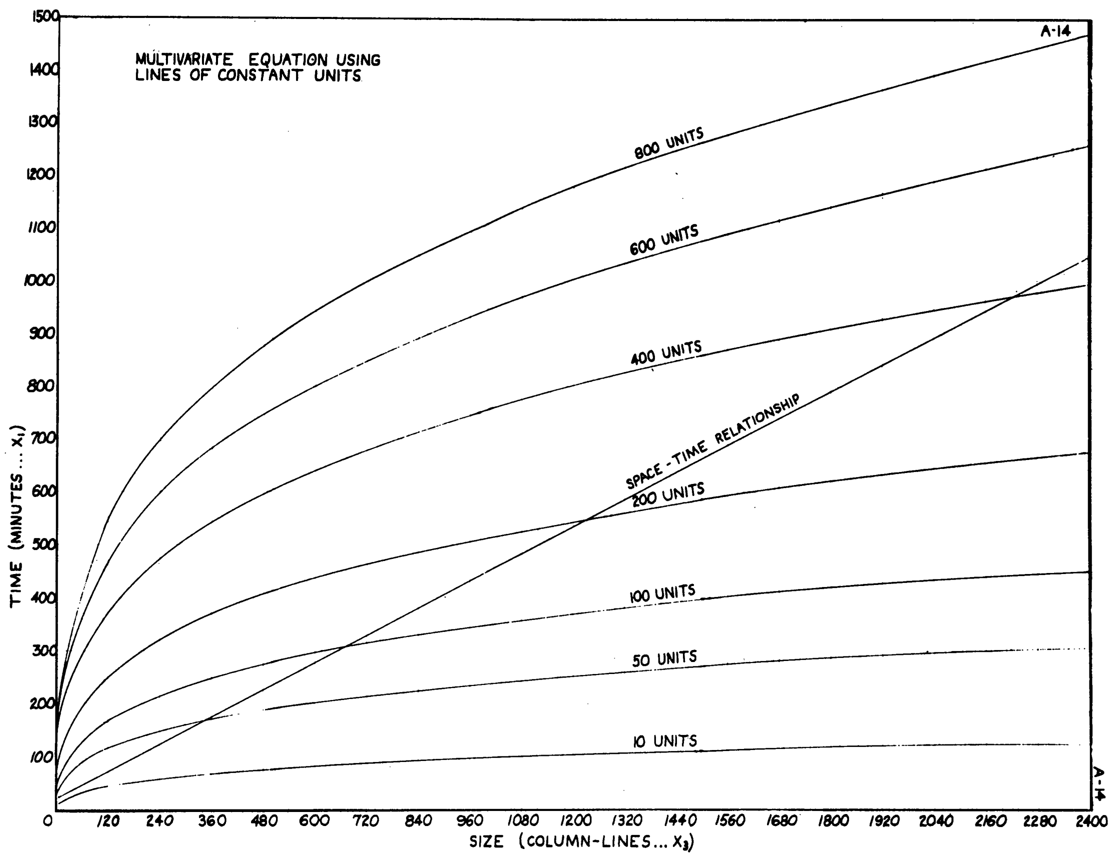
Slide 3

We then set about fitting a line to the data, and here our illusions went up in smoke, because the intercept on the y axis, in rectangular coordinates, turned out to be 56 minutes. This simply didn't rationalize. You cannot say that a constant for the composition of any ad is 56 minutes, regardless of its simplicity or complexity or size. One of the mathematically-inclined persons on the project then suggested that we examine the data on a stratified basis. When he did this, he got an intercept on the y axis for the larger ads somewhere around 300 minutes, which rationalized even less well, and for the middle of the sample, I think it was about 150. He thereupon suggested that we did not have a two-variable relationship, but a three-variable relationship, with ad size as a third vairable. This led, in turn -- I am skipping over an awful lot of exploratory work -- to the fitting of a plane, in logarithmic coordinates, to these data. And this gave us an equation of this form:

$$\text{Log } T = K + K_1 \text{ Log } U + K_2 \text{ Log } C$$

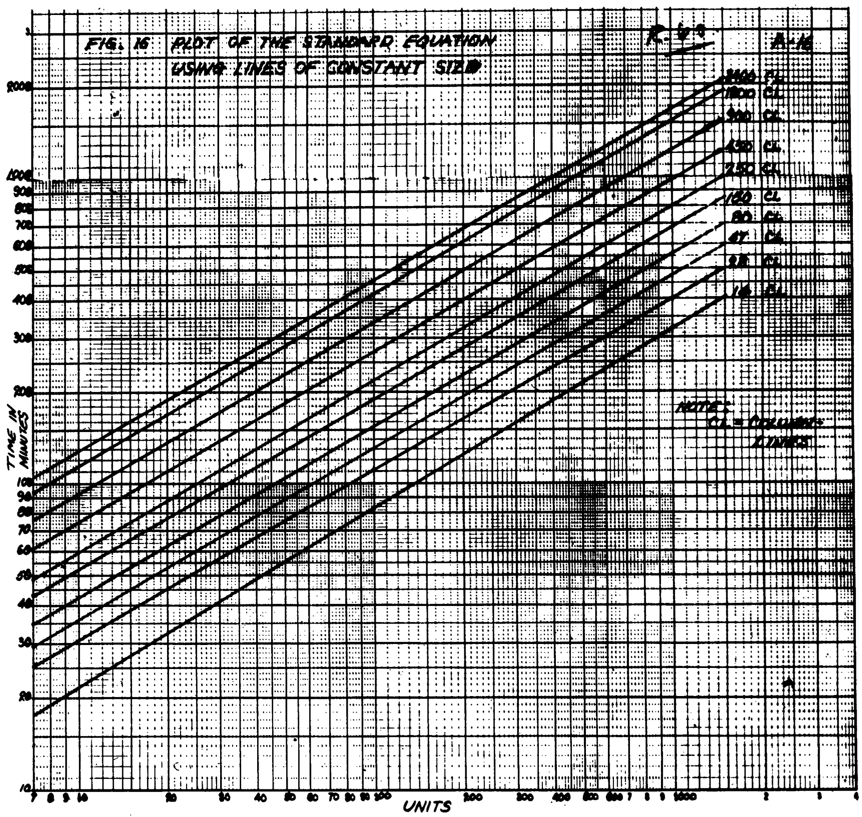
Where T is the time in minutes required for composition exclusive of store corrections, U is the number of units in the ad, as I've already defined them. C is the number of column lines in the ad, and this is a conventional measurement widely used in the industry. The constants are of such a nature as to give us several indications. We can make inter-newspaper comparisons by comparing the constants from such a measurement and there are also other uses which I will describe presently.

To give you some idea of what this looks like, I would like to show two additional slides. The first of these simply compares in a very crude way what we have done in a three-variable equation of the kind I put on the board with what the newspapers ordinarily do. They sell advertising on a space basis. There are discounts, and there are various categories



Slide 4

of ads, but in general, if you buy a 500 column-line ad, you pay twice as much as when you buy a 250 column-line ad. We have represented this by a straight line with rectangular coordinates, this being their conventional method of charging. The method of charging, if one based upon cost, would be according to the curves of constant units shown.

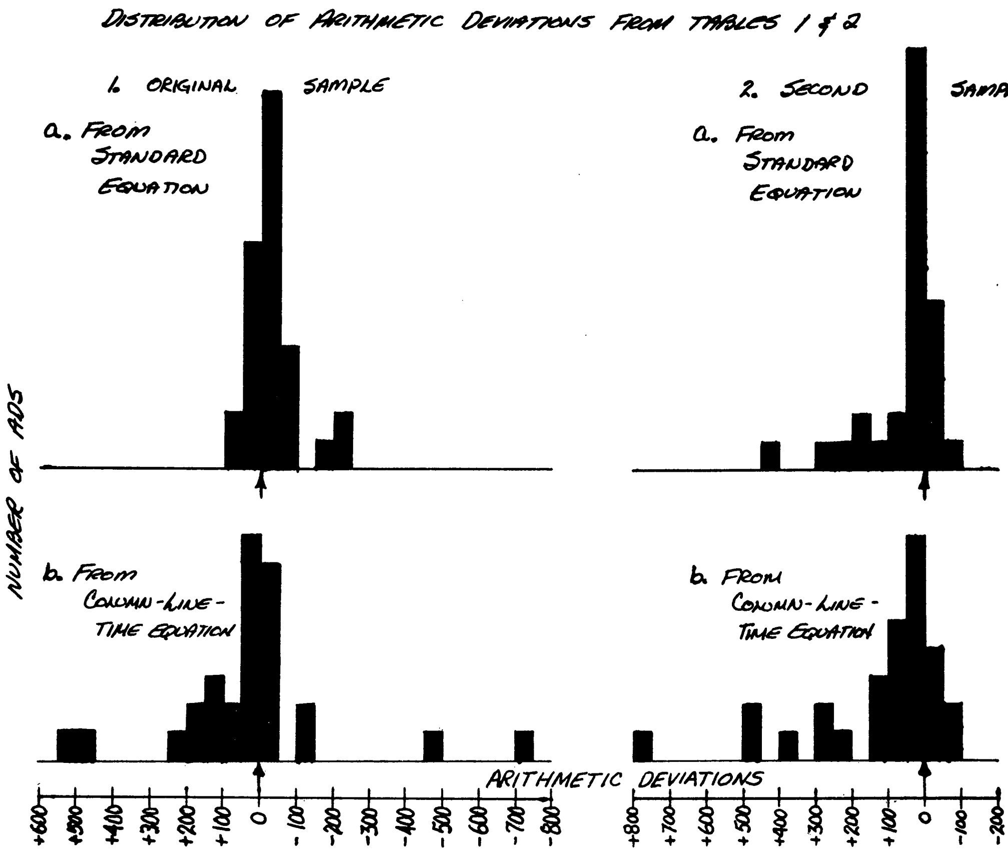


Slide 5

The second of these two illustrations shows a similar but more useful plot, on log-log paper with lines of constant size.

As I have said, this job was started initially with two newspapers and we made certain comparisons between them. We have since taken measurements in six other newspapers. The Detroit News was one of these but we have not yet finished processing the data on that particular paper. What is the usefulness of this particular document? Well, as I have already suggested, comparison of the constants by the substitution of values of column-lines and units in the equation makes it possible to make efficiency comparisons between newspapers. It is also possible for any given newspaper to measure its own efficiency from time to time, from accounting period to accounting period, by the summation of the standard times derived from the equation, divided by the sum of the actual minutes worked by the compositors. It is also possible, and this is at the moment just being completed, to establish a standard job cost accounting system, not merely for local display advertising but for all the component products manufactured by a newspaper.

I would like to conclude this case example by a few more slides. The first will give you some idea (I should have injected this earlier) of the relative accuracy of the three-variable equation and the conventional column-line - time relationship. This is shown by these histograms,



Slide 6

from the two separate samples of the same newspaper. These histograms are made by comparing the standard time computed from the equation with the actual time recorded from the data sheets which I showed you in the first slide. The next slide shows histograms from two different newspapers, indicating approximately the same kind of distribution. The equations are certainly not as accurate as one might wish, but are much more accurate than anything that they've had before.

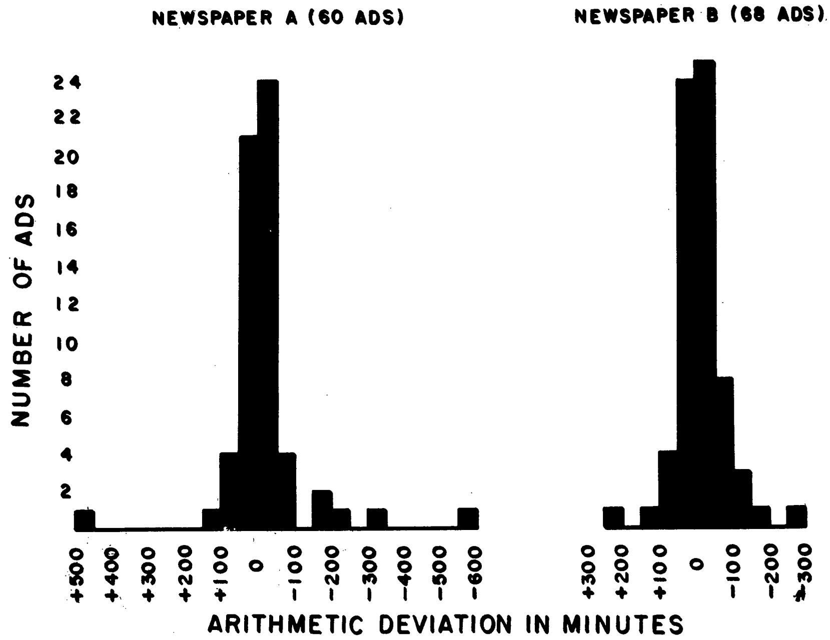


Fig. 4. Histograms showing the deviations of standard time from actual time for Newspapers A and B. The vertical scale gives the number of ads for each of the deviations shown along the horizontal scale. Positive deviations indicate that the standard time calculated from the equation is higher than that recorded by the compositors; negative values are for standard times less than that recorded by compositors.

For Newspaper A, 45 out of 60 ads show deviations between ± 50 minutes (21 from +50 to 0 and 24 from 0 to -50). For Newspaper B, a total of 49 out of 68 ads are predicted with the same accuracy.

Slide 7

We have proposed to the newspapers that they introduce with this a system of standard cost accounting. The next slide will indicate a simple time card by which they can keep separate, not the jobs worked on, which is absolutely impracticable, but the kinds of time. All we need to have measured are the intervals spent on local display advertising, as distinct from news, editorial, or other activities, job work and the like. We have also recommended, as indicated by the next slide, that newspapers begin to account, by means of elapsed time records, for what are called store corrections. These, on the first newspaper we studied, comprise 16 percent of all of the time devoted by all of the compositors on all ad operations. A very costly business. We hope ultimately that this will have an effect upon the rate structure of the newspaper. And, finally, the last slide is a computation table by which these calculations may be carried out. Since the equation is exponential, by looking at the nearest number of units in this column and taking from the second column a factor, and doing likewise for column-lines, the product of the two will be a standard time for the ad.

DATE AND TIME STOP W11.5	NAME OF PAPER COMPOSING ROOM TIME CARD	
DATE AND TIME START W3.5	NAME Doe	NO. 250
STARTING TIME	CLASS OF TIME	ELAPSED TIME
7:40	LDA	230
7:30	News	10
7:00	Supper	—
5:45	News	75
3:30	LDA	135

Fig. 5. Sample time card showing work intervals by class of time. Time clock recording for payroll purposes is shown at the top. Handwritten time entries and class of time are entered from the bottom up for convenience in subtraction. Elapsed time would be computed from these entries by the accounting department.

This sample is intended only to suggest how such a record can be kept; each newspaper can modify the form for its own purposes. Provision of space for payroll hours, for total minutes by class of time, and use of decimal hours and time clock recording, rather than handwritten entries, would be examples of possible modifications.

NAME OF PAPER

DISPLAY ADVERTISING CORRECTION RECORD

JOB NO. 215 ADVERTISER Sears COL. LINES 2400

Instructions for Use:

Dispatch: Attach one of these forms to every set of returned proofs bearing corrections made by the advertiser.

Compositors: Enter the job number, the name of the advertiser, the operation performed, your own number, and time start and stop in the appropriate spaces in the record. Do not detach the form; send it with copy and proof to the next operation.

Proofreaders: Enter your own work on the record as described above. When releasing proof either for dispatch to the advertiser, to page make-up, or to hold on file, detach the form and send it with all others collected to the accounting department at the end of each day.

OPERATION	DONE BY	TIME START	TIME STOP	ELAPSED TIME
Mark-up	199	10:53	11:10	17
Lino	216	1:43	2:21	38
Ludlow	38	2:35	2:42	7
Assembly	56	3:24	4:20	56
Revision	195	4:38	4:50	12

Fig. 6. Sample form for the recording of store correction operations. Modifications can be made at the discretion of each newspaper. Again it is assumed that elapsed times are calculated and posted in the accounting department.

Slide 9

NEWSPAPER A - FACTORS FOR CALCULATING STANDARD TIMES

Units	Factor	Units	Factor	Units	Factor	Col-Lines	Factor	Col-Lines	Factor	Col-Lines	Factor
1	3	126	34	476	64	7	1.9	290	6.8	880	10.0
2	5	134	35	492	65	10	2.2	300	6.9	900	10.2
4	6	144	36	506	66	14	2.5	310	7.0	950	10.4
5	7	152	37	522	67	20	2.7	320	7.1	1000	10.5
6	8	162	38	540	68	21	2.8	330	7.2	1050	10.7
8	9	170	39	556	69	25	2.9	340	7.2	1100	10.9
10	10	180	40	572	70	28	3.1	350	7.3	1150	11.1
12	11	190	41	590	71	30	3.2	360	7.4	1200	11.2
16	12	198	42	608	72	40	3.4	370	7.5	1250	11.4
18	13	208	43	624	73	42	3.5	380	7.5	1300	11.6
20	14	220	44	642	74	50	3.7	390	7.6	1350	11.7
24	15	230	45	662	75	56	3.9	400	7.7	1400	11.8
26	16	242	46	680	76	60	4.0	420	7.9	1450	12.0
30	17	252	47	698	77	70	4.2	440	8.0	1500	12.1
34	18	262	48	716	78	80	4.4	460	8.1	1550	12.2
38	19	274	49	736	79	90	4.6	480	8.2	1600	12.4
42	20	286	50	754	80	100	4.8	500	8.3	1650	12.5
48	21	298	51	774	81	110	4.9	520	8.4	1700	12.6
52	22	310	52	794	82	120	5.1	540	8.5	1750	12.7
58	23	322	53	814	83	130	5.2	560	8.6	1800	12.9
62	24	334	54	834	84	140	5.3	580	8.7	1850	13.0
68	25	348	55	856	85	150	5.5	600	8.8	1900	13.1
74	26	362	56	878	86	160	5.6	620	8.9	1950	13.2
80	27	374	57	898	87	170	5.7	640	9.0	2000	13.3
86	28	388	58	920	88	180	5.8	660	9.1	2050	13.5
92	29	402	59	942	89	190	5.9	680	9.1	2100	13.6
98	30	416	60	964	90	200	6.0	700	9.2	2150	13.7
106	31	430	61	986	91	210	6.1	720	9.3	2200	13.8
112	32	446	62			220	6.2	740	9.4	2250	13.9
118	33	460	63			230	6.3	760	9.5	2300	14.0
						240	6.4	780	9.6	2400	14.1
						250	6.5	800	9.7		
						260	6.6	820	9.7		
						270	6.7	840	9.8		
						280	6.8	860	9.9		

Fig. 3. Table of units, column-lines, and factors for the calculation of composition standard times at Newspaper A. To use this table select the next lower number of column-lines and units, and multiply the factors for each. For example, assume that a given ad contains 452 column-lines and 77 assembly units. The respective factors are those shown for 440 column-lines (8.0) and 74 units (26). The product of these factors 8.0 x 26 = 208 minutes, the standard composition time for the ad.

Slide 10

Admittedly, this case smacks somewhat more of industrial engineering than of OR, but I would like to make this remark apropos of the work we have done. The team consisted of a professor of accounting, a professor of psychology, a professor of industrial engineering, graduate students who were writing their essays in part on the work they have done with us, an associate professor of statistics, and an assistant professor whose specialty has been in waiting line theory. I would freely admit that one might conceive of a better team than this, and indeed we contemplate bringing on to the team a member of the economics staff in the field of labor relations as soon as we begin to tangle with that sensitive area, which will not be in the too distant future.

In any event, I have tried to give you an example of the ability of a university and an industry to engage cooperatively in OR under circumstances where the industry, being composed of small units, itself would not have had the resources nor the insight to do this kind of work. We think that this is working out fruitfully for them; we are quite sure it's working out fruitfully for us and we hope very much that we shall continue on and on into the foreseeable future. I am scheduled tonight to go to Chicago, to meet with four publishers and, if you will convene this meeting again on Thursday, I'll be able to tell you better. Now, Professor Thrall, I have finished on time and get a bonus.

OPERATIONS RESEARCH FROM THE MANAGEMENT VIEWPOINT

M. L. Hurni
Manager, Operations Research & Synthesis Consulting Service,
General Electric Company

I believe you will agree with me that in business we deal with complex phenomena. What incoming order rates signify, the effect of product variety on cost, or capacity, the effect of volume on cost, the effect of variety on machine capacity, to mention a few, are illustrations of the kinds of phenomena that I have in mind.

I believe you will also agree that in business we deal, more often than not, with situations that involve dealing simultaneously with a sizable number of factors which are interrelated into an organic whole. These are situations that are too complicated to yield to the familiar and rigorous techniques that were so dramatically successful on two, three and sometimes four variable problems of the kind we learned about in school.

I believe it is also safe to say that if we can find ways of treating with these kinds of situations more effectively than we now do, these ways would be welcomed.

All too frequently we are now required to think in simple terms about complex phenomena and to reason simply about multi-factor situations, and then extrapolate to the complex, real-life situation. This is the burden and risk of Managers.

If we could reduce complex phenomena to something we as men can again grasp, but without losing the essence of the essential complexity, this should represent progress -- our intuition or experience as Operating people would be substantially enhanced.

If we could observe how situations involving many factors simultaneously are likely to perform as the factors involved are varied, our understanding of what to do to accomplish specific purposes would be markedly enhanced.

We think that in the kind of work that has come to be called Operations Research, we have a means to begin accomplishing this purpose. For emphasis, I repeat -- a means to begin accomplishing this purpose.

We have no illusions that the starts will immediately show brilliant and elegant results. We recognize that the work will be slow and plodding, the results at first meager but of increasing impact, as time goes on. You will find in the illustrations used today, that the results of the work, while providing some increased understanding, also raise many new questions, and suggest new avenues for exploration. What may well be significant is the fact that questions are raised that were not raised before, while we as Managers, of necessity, reasoned more simply.

As we have studied the subject and seen work start, we see further that there is in this concept a means for building into and out from simple beginnings into structures of information that more closely approximate real-life situations.

Those of you who are familiar with the history of the Physical Sciences can draw many analogies to how results come, and how they may be used, and the distinctions between this kind of effort and Operating work.

It is important that you as Managers draw this distinction. To use this work, it is necessary to organize for it, to define purpose, responsibilities, authorities and relationships stemming from the purpose.

We feel that the purpose of Operations Research work is to develop better understanding of how business entities are likely to perform. We feel that through such clearer understanding, Operating people will be able to make crisper decisions, and that better integration of efforts to common purposes will come. There is a two-way effort here:

1. Doing the work to create a basis for better understanding of the complex situations with which we deal -- which is Operations Research work.

2. Understanding the results and applying them as imagination and experience dictate in Operating situations. Just as we do with that which is available to us now.

To sum up at this point, I have, in effect, been asking myself two questions:

1. Is there a need at this time for better and perhaps more thorough understanding of how business entities perform?

2. If it is feasible to get such understanding, is it worth while to devote people and effort exclusively to acquiring and disclosing such augmented understanding?

These are questions that you as responsible Business Managers must also ponder, if there is to be an understanding of what has been said today and a knowledge of how to use work of this character.

Complexity

To divert for a moment, I mentioned earlier the complexity of phenomena with which businessmen deal, and the need to reduce such information to a form where the complexity can be grasped and changes in it observed and measured.

I would like to illustrate what I mean with a simple example. On this roll of paper are one thousand pieces of information. They are daily requests made on a warehouse for a single product. The size of the daily requests varies from one unit per day to around 70 or 80 units per day. These requests or demands do not occur in any orderly fashion. Yet, we must carry a stock of units at the warehouse in order to meet customers' requirements by some standard.

It is reasonable to assume that out of these data, we should be able to get a picture of how the market for this product performs that could form a basis for a stocking plan, in accordance with some standard, as well as a basis for indicating when a change in the stocking program is in order, if the standard of performance is to be met.

If there is to be a basis for common understanding between the warehouse and the Product Department so that changes can be made with mutual confidence and performance evaluated objectively a means must be available for understanding the phenomena and reasoning about them.

But here is the data and everyday more of it is ground out. It is everday data, but it is not simple data. Today the requests for the particular product under discussion are only one; tomorrow, ten; the following day, 50; the next, zero. And so it goes, not just for one product at one warehouse, but for many products at many warehouses.

As Operating people do we need to understand such data in the first place -- particularly in these days of rising costs, of continually mounting social expectations and mounting taxes -- in order to sharpen our operations?

In the second place, can we understand it, in its volume, its variety and its ceaseless generation, just by looking at it, by speculating about the conference table, or do we need to do more than this?

Do we need systematic study and the application of scientific method such as you have heard about today to disclose the significance of this pulsing phenomena, its relationship to and impact upon risk, cost, or service standards to mention a few?

Foundations and Feasibility

To return to the main theme again, our concern with complex phenomena and multi-factor situations. The foundations of this work go back as early as 1900 in the work of such men as Pierre Duhem on Thermodynamics, and the American, Josiah Willard Gibbs, in Chemistry and Mathematics.

We could spend a number of days on this subject alone. The basic ideas are a little strange and perplexing to those of us who, like myself, received an engineering or scientific training a quarter-century ago. We didn't hear about these things, these ways of looking at and evaluating the world about us. In my opinion, they have had their first important use in the field of nuclear physics, where it was finally perceived that you could not understand nature completely as a set of cause and effect relationships To put it another way, there were large areas of natural phenomena that could not be understood by how the mechanism works. The best that could be done was to describe how the "black box" would most likely perform. It was, of course, discovered that this kind of understanding could serve useful purposes, and purposes intractable to the "how does it work" approach.

For those of you who are interested in exploring these foundations, I'd like to suggest four books:

Cassirer's - "Determinism and Indeterminism in Modern Physics"
Duhem's - "The Aim and Structure of Physical Theory"
Ashby's - "Introduction to Cybernetics"
Allen's - "Mathematical Economics"

These books should be read for their philosophical content, for their method of approach to other problems of similar depth and complexity to those that confront us as businessmen. From such reading, inferences to our business situation should be drawn by the reader. From them also will come an understanding of the foundations underlying the cases you have heard today, and a feel for the underlying confidence our speakers have had in the feasibility of doing this type of analytical research and theoretical synthesis broadly across a business.

Let me illustrate the foundations briefly. In his paper, "Science and Complexity," which appeared in the "American Scientist," Autumn Issue, 1948, Warren Weaver describes three classes of situations to which Science has and is addressing itself:

1. Problems of Simplicity -- where it is possible to hold constant at all times all variables except possibly one or two, and observe the effect of varying literally one at a time. In his view, Physical Science up to around the turn of the century was concerned with and capable of treating only these kinds of problems.

2. Problems of Disorganized Complexity -- These are problems in which the phenomena cannot be precisely described, and for which the techniques of probability theory and statistical mechanics were in time developed to bring understanding.

   Recognition of how to treat of such problems began about the turn of the century with Gibbs and Duhem.

   Feasibility is here seen in Thermodynamics and Nuclear Physics, for example.

3. Problems of Organized Complexity -- This is the latest development and is concerned with dealing simultaneously with a sizable number of factors which are related into an organic whole.

   Mathematical programming, axiomatic algebra, are giving important impetus to feasibility in this field.

During the war, it began to be recognized that many problems of human performance and of the performance of organizations of humans were, in reality, either problems of disorganized complexity, organized complexity or both. One distinction should perhaps be noted, although it is not unique. This is, that the basic phenomena themselves may not be unchanging as we presume in the Physical Sciences. But the effect of change is predictable, and if steps are taken to measure change -- systematic and rigorous knowledge is possible.

Curiously enough, what was studied during the war was not specific logistic or combat problems, but the actions of elements that went into such problems and their interaction on each other.

For example, there were detailed classifications of how submarines attacked, how aircraft came over various areas to be protected. Since they never came exactly the same, each time, the patterns were not only noted, but also their frequency of occurrence. From this, came a new vision of these things, far superior to the casual observations of those in combat.

By so classifying and describing these phenomena, it also became possible, as more information was collected, to theorize about such matters away from the heat of battle. Out of this came new ways of observing the enemy in combat, of measuring his performance, and of evaluating countermeasures.

It is interesting to observe here that the research people were not solving specific problems, or making decisions, or directing specific engagements, but providing information that made it possible for the combat officer to do his job more knowingly and more sharply in certain kinds of situations.

Risk was not eliminated, but we might say that out of such work the unknown began to take form and also specific probability.

After the war, a number of men who had been involved in this work began to study business situations. As a result, a substantial amount of investigation of isolated situations in business has been conducted. The results thus far are reasonably well summed up in three fairly recent books:

"Operations Research for Management" Volumes I & II from Johns Hopkins

"Introduction to Operations Research" from Case Institute

These are compilations of Research Work, basically. As they stand, they might be likened to research in solid state physics to the development of transitors. What they do demonstrate is substantial interest and a body of knowledge for go power.

Perhaps the most significant synthesizing work after the war was Wiener's "Cybernetics." Wiener pulled together a lot of isolated thinking into a concept. In effect, he added one more concept to our notions of how to understand the world about us in a purposeful way.

The classical concepts are:

1. What is this thing -- this is the Linnean classification so typical of botany and biology and the so-called Life Sciences.

2. How does it work -- the cause-effect approach of Auguste Comte and the distinguished line of Newtonian scientists and engineers.

To this, Norbert Wiener added the third:

<u>How does it seem to behave</u>

What caused impact here was his ability to demonstrate that this concept could be implemented and that it brought understanding where difficulty was being encountered in applying the classical approaches. He could understand the simulate, even though he didn't know how the entity under study worked.

Starting in the field of neurology by studying the manner of behavior of a mouse under certain circumstances, he was able to simulate the mouse. His simulation, which was electronic and not a mouse, did the things he planned for as a machine, and also, displayed other mouse-like reactions not planned in an engineering sense.

He secondly developed a kind of hearing aid for the totally deaf, based upon his understanding of the performance of nerve endings.

The monumental work, thus far, using this approach is that leading to and including Claude Shannon's Mathematical Theory of Communication which is based upon the observation the the communication of intelligence is probabilistic in nature.

Without knowledge of the mechanism for communicating intelligence, but by observing the behavior of "black boxes" -- people -- in the act of communicating, he was able to propose a theory of communication that will keep telephone people busy for years.

We have here --

1. Observation of seemingly repetitive activities

2. Hypothesizing for the purpose of simulating and predicting outcomes beyond those otherwise attainable.

Now, electronic mice, hearing aids for the totally deaf, the Mathematical Theory of Communication, or for that matter, these three volumes of research papers, are of little use to us as practical men of affairs.

Assuming for the moment that such investigation is feasible and needed, can it be done purposefully, or only by accident? Can it be done on a continuing basis, if it can be done purposefully, are important questions to be answered.

This again is a subject that might be discussed for hours, if not days. With your permission, I would like only to state some concepts or viewing points which in our opinion make this possible. There are probably three main concepts that inform the Operations Research worker.

1. The Repetitive Pattern of Operations

In a speech given at the International Institute of Statistics at Rio de Janeiro, Brazil, in August, 1955, Dr. Philip M. Morse presented an excellent exposition of this concept. The essence of the idea is expressed in the following paragraph which I quote from Dr. Morse's paper:

> "One class of human activity that seems to be amenable to the techniques of mathematical model making and quantitative experimentation is the repetitive group action that is often called an operation. A battalion of soldiers doing its assigned job, a squadron of planes on a mission, a running factory or a sales organization is more than a collection of men and machines; it is an activity, a pattern of operation. These operations can be studied, their regularities can be determined and related to other operations; they can eventually be understood, and they then can be effectively

modified and improved. Their repetitive nature, and the fact that they often involve and are conditioned by equipment, apparently makes these phases of human activity much more amenable to the quantitative analysis of physical science than most social and individual animate action."

The entire paper is worth reading for the full development of this concept and the results.

2. The Rational Nature of Decision-Making

In such operations, we note that people act as sensing devices and nervous systems. Decisions are made based upon observation, information, experience and knowledge to keep the operation going in accordance with plan. Decisions are also made that modify the plan and, therefore, the operation.

Close observation of the foundation for decisions, that are not so repetitive as to become routines, indicates that they are made on a logical basis. This is most clearly evident when one observes decisions that are made to modify the plan of operation, to wit:

- Assumptions are made
- Objectives are derived and stated
- Alternate plans of accomplishing the objectives are developed
- A plan is selected and implemented
- Measures, compatible with the plan, are derived
- Measurements are taken and evaluated, and
- Modifications are made, if required.

This brings insight to the Operations Research worker concerning what he may do to improve the rationality of such decision-making.

For example, all too frequently the assumptions made are opinions. These may be the opinions of experienced people, but they are opinions. They are difficult to convey to others with understanding. There is no basis for examining their validity. They must be accepted on the basis of the past performance of the individual whose opinion is taken.

What is preceived is the opportunity to describe phenomena in concise form upon which assumptions may be based by such people, which may be used in the testing of the validity of assumptions made and which may serve as a basis for understanding the nature of the assumption.

A quick example taken from a larger piece of work may illustrate the point.

In making plans for a new manufacturing facility, it was assumed that incoming orders were so erratic and competition so keen, that it would be necessary to build a plant capable of meeting peak loads in order to obtain reasonable volume. Since the business in question offered for sale some 12,000 discrete models of product, this assumption was exceedingly difficult to evaluate, although firmly held. Leading from this assumption, a prohibitive plant investment was inevitable.

Over a year's period, historical data were systematically collected and scientifically processed to reveal and convey information in respect to this assumption. The models of product were carefully studied, not from the standpoint of the sales handbook or the accounting classifications, but rather for generic simularities that might make sense in the manufacturing operations, as a basis for characterizing the flow of orders.

Out of this came a demonstration that over the preceding five years, the actual flow of orders for roughly 90% of the models, including the bulk of the volume, had been exceedingly stable for periods of between 6 and 18 months at a time, depending upon the particular generic family. Changes, when they did occur, were sufficiently reasonable as to permit normal adjustments without jeopardy to performance standards.

The mere ten per cent of odd items had been responsible for the impression that the business was erratic.

Not only, therefore, was the established assumption invalidated, but by studying the phenomena of inputs, a basis was provided for those people concerned with the success of the operation, to come instead to a better reasoned and understandable assumption in respect to the nature of the order inputs.

The central point here is that this concept provides insights on how to bring systematic discipline and scientific method to bear in respect to the needs of Managers in the area of their responsible decision-making.

3. Viewing the Business Enterprise Itself as a System

The third concept is that a "business" may be represented as a system.

This simulation may be similar to the electrical engineer's system used to represent electric apparatus for the purpose of studying performance in abstract, the communication engineer's system, or the system of the econometrician. Each is, or all are, an approximation of the business itself. It is a model of the real thing.

This model, system or hypothesis of the business permits the identification of the gross elements entering into the conduct of the business. It informs in respect to what elements can and should be studied for their impact upon the whole.

Being an abstract representation, it permits exploration of the sensitivity, the range and the impact of various elements as they are varied; and it thereby can make more explicit the consequences of courses of action, the risks, opportunities and conditions for achievement, the topology of results in areas where plans or programs are to be initiated.

It also fits into place, and gives relevance in the total picture, to pieces of Operations Research work done in the separate but inter-related functional areas:

- It provides a basis for the systematic study of the hypothesis, the assumptions on which it is based and the expectation it is intended to achieve

- Systematic study and continued work on such a system, result in concise, communicable description of the elements to appropriate individuals within the enterprise

- Quantitative abstraction brings a broader range of, and a more rigorous approach to, the process of manipulating the hypothesis for topological exploration of risks, opportunities, restraints, to mention but a few

- Quantitative abstraction brings with it the opportunity to describe concisely what has been done; what is expected to be accomplished; and how, and above all, to develop the ability to establish measure indicative of the degree of success of the business experiment over a period of time and the areas in which purposeful modification may be required.

The pertinent point, here again, is that this concept focuses on the needs of Managers, and informs the Operations Research worker where and how to proceed to do his work in a fruitful manner from this point of view.

In light of what has been said about the nature of such work, it seems appropriate to inquire about the nature of the results of Operations Research work.

Any attempt to describe the results as such is difficult because of the variety of forms the results may take. In the time available, it seems appropriate only to state the generic classes of results known to be available.

The results of this work will be of two kinds:

1. Description of the premises and objectives on which the business is or could be based and the interactions within the business system itself through:

   a. Classification
   b. Structuring
   c. Characterizing

   which permits one to also ask the questions: Is this consistent? Is it complete?

2. System or theory building through:

   a. Codification of existing beliefs about the business into coherent form; and also the existing ideas in place for implementation

   b. Modifying such theories on the basis of what is learned from the descriptive activities

   c. Building models, or designs in the abstract, of possible system to implement such beliefs effectively.

Both of these activities may go on at the same time or they may take place in sequence. They may be directed toward obtaining a clearer description and understanding of a business -- a better common vision for Functional Individual Contributors and Managers; or they may be directed toward obtaining a clearer insight into the nature of certain central problems confronting a business.

The results of such work are structures of information and knowledge. Such results are permissive. They compel no one to do anything. They are useful only as they are understood, accepted and implemented in operations by Managers or by appropriate Individual Contributors.

The result of the work we have come to call Operations Research is theory building about large, complex entities such as the whole of a business or its important parts. Such theory is intended to simulate the performance of the real thing with varying degrees of approximation, and we expect with increasingly better approximation. The purpose is to provide better and more complete understanding for those who have the responsibility of operating.

The results might be likened to those of Clerk Maxwell in respect to General Electrical Theory or that of Pierre Duhem in respect to the Statistical Theory of Thermodynamics. The analogy is a crude one, to be sure. Maxwell's and Duhem's Theories represent ultimate culminations. We here are only starting. But the likeness of these theories to practical engineering work is a good one.

Now, you may say this is presumptuous. The only reply to this is, that you are already doing this kind of theory building now. You are doing it part time, either consciously or unconsciously. You are doing it without the benefit of the tools and skills that are available now to be brought to bear to this task.

We are convinced that an humble start can be made to bringing these available concepts and methods to bear on this work. We are further convinced that although the beginnings will be humble, by setting aside people to do this work as a specific, assigned responsibility, there are inherent potentials for increasing refinement. We are also convinced that early results can and will be useful, even where theories are incomplete or only one step removed from those we unconsciously develop in our daily work.