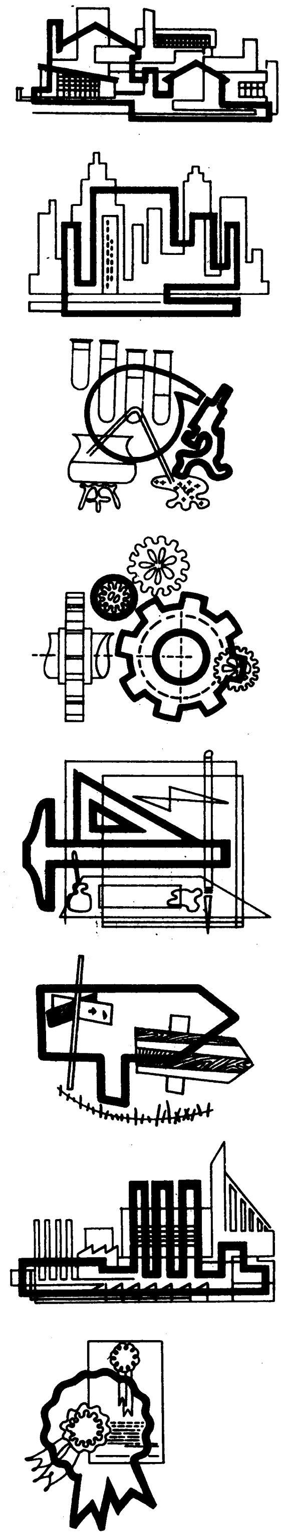
PROCEEDINGS



5TH ANNUAL INDUSTRIAL ENGINEERING INSTITUTE

UNIVERSITY OF CALIFORNIA

BERKELEY January 30-31 1953 February 2-3 LOS ANGELES

PROCEEDINGS

FIFTH ANNUAL
INDUSTRIAL ENGINEERING
INSTITUTE

D. G. MALCOLM, Editor
Vice President, Engineering and Production
Bacon Vulcanizer Manufacturing Company
Oakland, California

UNIVERSITY OF CALIFORNIA

BERKELEY

Friday and Saturday
JANUARY 30 and 31, 1953

Presented by:

DIVISION OF MECHANICAL ENGINEERING

INSTITUTE OF INDUSTRIAL RELATIONS

SCHOOL OF BUSINESS ADMINISTRATION

UNIVERSITY EXTENSION

In cooperation with:

AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.

SOCIETY FOR ADVANCEMENT OF MANAGEMENT

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

LOS ANGELES

Monday and Tuesday
FEBRUARY 2 and 3, 1953

Presented by:

COLLEGE OF ENGINEERING

SCHOOL OF BUSINESS ADMINISTRATION

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AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.

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For those interested in some of the technical details in the publishing of these Proceedings

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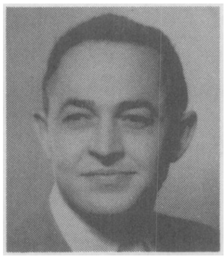

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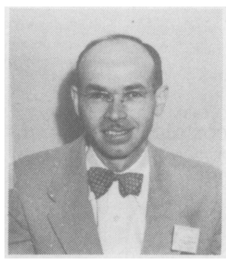

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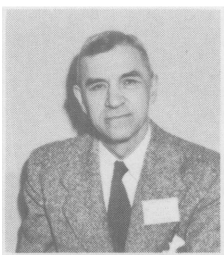

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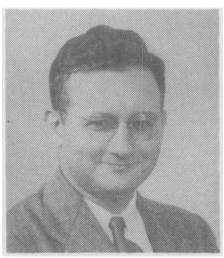

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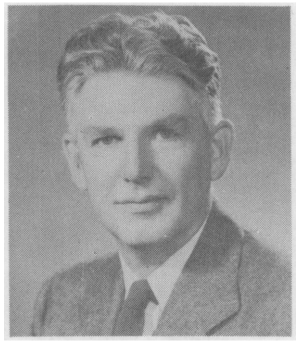
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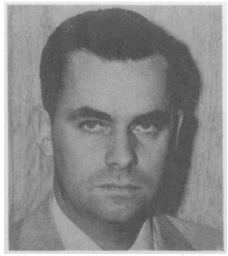
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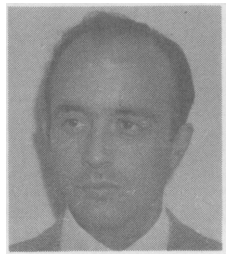
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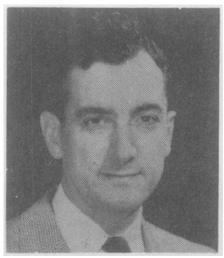
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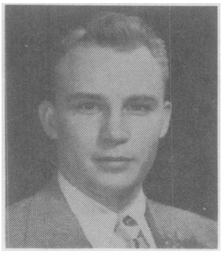
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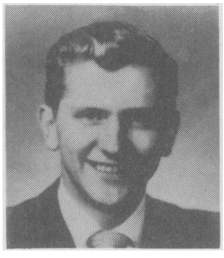
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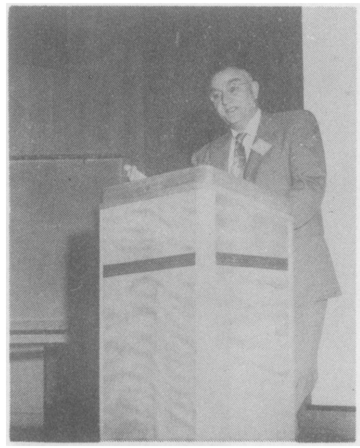

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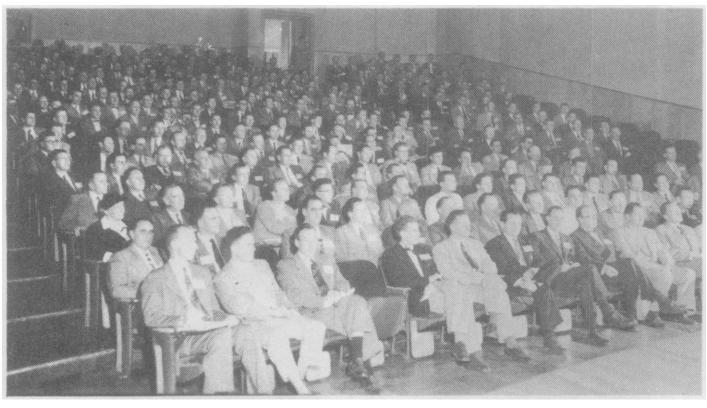


View of part of audience in Dwinelle Hall, Jan. 30

Dean N. H. Jacoby luncheon Feb 3

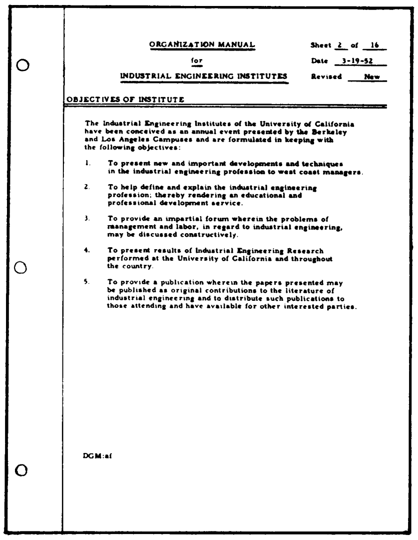
FOREWORD

The papers delivered at the Fifth Annual Industrial Engineering Institute are present for your review and dissemination. In reviewing these papers I have been greatly impressed by the amount and diversity of the subject material covered at this year's conference. The engineer in industry is truly being called upon to design, predict and evaluate the performance and cost of ever increasingly complex systems. How the industrial engineer, dealing primarily with systems of people organized toward the goal of productivity, is meeting this challenge is aptly demonstrated by the content of the papers presented.

The response we have had to these annual conferences has been amazing and, in all humility, it has been a real challenge and responsibility to live up to the objectives we have set for these meetings. The production of these objectives as appearing in the Organization Manual for the Institutes indicates the blue-print by which these institutes have been constructed.

In my opinion these objectives are all of relatively equal importance. When it is attempted to determine how well we have met these objectives, we have found ourselves in much the same position as is management of a corporation when it attempts to measure precisely the efficacy of any given technique or program. We can only recite a few interesting statistics that prove continued profitable existence and growth. The real measure of success lies within the minds and hearts of those involved.

In this vein, we do know that attendance has grown as shown by the following:



ORGANIZATION MANUAL
for
INDUSTRIAL ENGINEERING INSTITUTES

Sheet 2 of 16
Date 3-19-52
Revised New

OBJECTIVES OF INSTITUTE

The Industrial Engineering Institutes of the University of California have been conceived as an annual event presented by the Berkeley and Los Angeles Campuses and are formulated in keeping with the following objectives:

1. To present new and important developments and techniques in the industrial engineering profession to west coast managers.
2. To help define and explain the industrial engineering profession; thereby rendering an educational and professional development service.
3. To provide an impartial forum wherein the problems of management and labor, in regard to industrial engineering, may be discussed constructively.
4. To present results of Industrial Engineering Research performed at the University of California and throughout the country.
5. To provide a publication wherein the papers presented may be published as original contributions to the literature of industrial engineering and to distribute such publications to those attending and have available for other interested parties.

DGM:af

ATTENDANCE

Year	Berkeley	Los Angeles
1949	133	
1950	256	
1951	220	
1952	360	230
1953	410	305

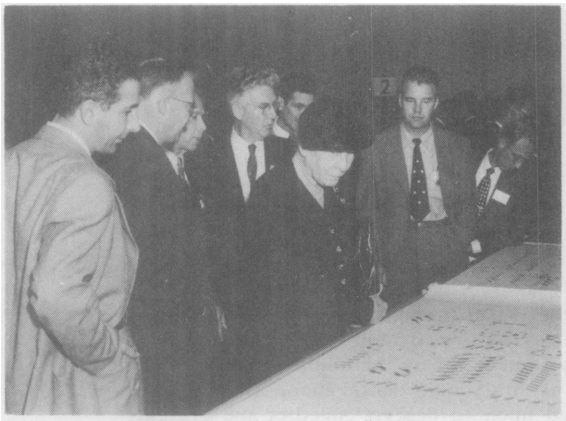
We also know that we have received requests for copies of the Proceedings of the Institutes from all over the United States, from Canada, Mexico and South America, from Australia and India and from almost all of the countries in Europe, excluding the countries behind the iron curtain.

We also obtain another indicator of our meeting these objectives in the form of the results of an interest questionnaire distributed near the end of each conference. A tabulation is included at the rear of the proceedings. Results of such questionnaires have guided the planning, encourage growth and the changing content of the meetings. This year's attention to the problems of smaller business is a direct result of knowledge gained from this source.

In the final analysis, the success of any endeavor is the result of the enthusiasm and effort of the people involved in the enterprise. We have been extremely fortunate to have had such a capable and willing "volunteer" staff. Their pictures, which are shown on the pages following, are but small tribute to the contribution of time and effort they so freely gave. Acknowledgement should also be made to Helen Hammarberg, Jack Dillon, Martin Andersen, and Dorthea Hightower of the University Extension for the efficient administrative handling of the Berkeley and Los Angeles meetings. Finally, to my secretary, Miss Margaret Belsit, goes a word of thanks.

It is our sincere hope that you will be with us next year for the Sixth Industrial Engineering Institute.

GENERAL CHAIRMAN



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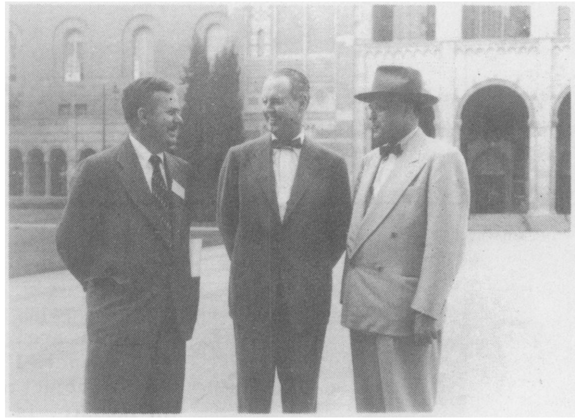

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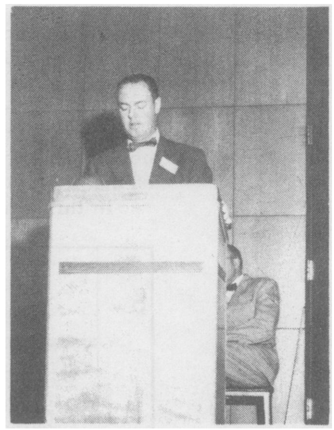
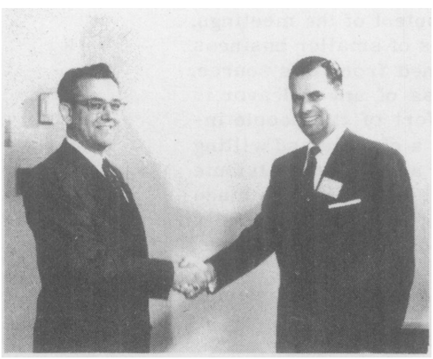


Introduction of L. D. Miles by C. N. Sandland



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WELCOMING REMARKS

WELCOMING REMARKS TO FIFTH ANNUAL INDUSTRIAL ENGINEERING INSTITUTE*

E. Paul DeGarmo
Assistant Dean, College of Engineering
University of California

It has been the custom in each of these Industrial Engineering Institutes to have the session opened by a welcoming talk given by some one from the administrative staff of this University. This has not been a mere formality, but instead an indication of the importance which this University places upon these Institutes. Dean O'Brien of the College of Engineering was to have given the welcome this morning, but was called out of town and after some uncertainty as to who would be in town during the period between semesters, the pleasant task of welcoming you, has fallen to me. I know that Dean O'Brien regrets his inability to be here since he is a most enthusiastic supporter of the Industrial Engineering program at the University of California and of these Institutes. For two reasons I look upon this opportunity to greet all of you with considerable pleasure.

First - it gives me a chance to look into the audience and see a very considerable number of former students of mine whom it is always pleasant to see again. My desire to convince myself that I am still just a young fellow overcomes my urge to ask those of you who are former students of mine, either in regular university or extension classes, to hold up your hands so that I may see just how large a percent of this audience you constitute.

Second - it gives me an opportunity to convey to you some conclusions which have come to me in recent weeks regarding the status of Industrial Engineering in this area.

This University's conception of education is somewhat different from that of a politician by the name of O'Rielly, whom I heard about recently. It seems that in an eastern city Mr. O'Rielly, who was one of those extremely valuable people and who was a graduate of the first or second grade of public school, and the "University of Hard Knocks", had decided to run for the office of Mayor. Some few weeks before the election one of his friends came to him and told him that if he expected to win the election he was going to have to brush up on his education a bit. O'Rielly, being an astute individual, decided this was good advice and so during the remaining three weeks of the campaign he not only carried on his political activities, but by various tutors, night school and correspondence courses finished what he was sure was equivalent to a complete high school education. His activities, both political and educational, were so successful that he won the election by a large majority. Convinced that his newly acquired education had played a key role in his success, he closed his inaugural address with the following words: "As George Washington said in his Gettysburg Address, 'Damn the torpedoes, - go ahead.'"

This University does not subscribe to the theory that a thorough education is easily acquired, nor that it can be acquired in its best form solely by graduating from high school and then spending four years within our "hallowed walls". Instead the educational process should continue throughout life and it is to this thesis that many of this University's endeavors are directed. We, therefore, look upon these Industrial Engineering Institutes as a very important part of the University's contribution toward this continuing education process.

It has been my very pleasant and somewhat unique experience to be in a position to see the development of Industrial Engineering on this Pacific Coast and particularly in the Bay area over the past fifteen years. We at the University have tried to contribute to this development and have felt that we have been able to be of some real help. During the past two years, I have come to the conclusion, from talking to Industrial Engineers and other executives from industry, and to engineering educators throughout the East and Middle West, that Industrial Engineering in the San Francisco Bay area is farther advanced both in practice, and in the high quality and thinking of the men involved, than in most other parts of this country. I say this, while knowing that these words will be published in the Proceedings which are widely read throughout the country. Numerous Industrial Engineers in other parts of the country have told me of practices and conditions which exist in their areas, and when they compare these conditions and practices with what I have been able to tell them about the situation in this area, they have agreed with my conclusion. In fact, I might more correctly say they have forced this conclusion upon me.

While we at the University like to feel that formal course work which we have offered and our graduates are partially responsible for this situation, I believe a much larger share of the credit must go to you men and women, most of whom are not today new-comers at this Institute, and who through the years by your very keen interest and activities in such affairs as these Institutes have shown a spirit of constant self-criticism and examination and willingness to come together to learn new concepts and discuss together your collective problems. Such conditions do not exist in many parts of the country.

One area of activity in which we feel we have not yet begun to achieve the results which we would like to see, is that of the problem of Industrial Engineering and other engineering activities in very small plants having less than 100 production employees, which are typical of this area. We have a number of plans in mind regarding this problem and the session which follows this morning is one of our attempts to put an extensive program into effect with respect to this situation.

I hope and I am sure that you will find the sessions of this Fifth Annual Industrial Engineering Institute which follow, to be helpful and stimulating. We look forward to having you return each year and assure you that it is an honor to have you in attendance at this Institute on our campus.

*L. M. K. Boelter, Dean of the College of Engineering, University of California at Los Angeles delivered the welcoming remarks at the Los Angeles session.

THE SIXTH ANNUAL INDUSTRIAL ENGINEERING INSTITUTE WILL BE HELD ON THE FOLLOWING DATES

BERKELEY - January 29, 30, 1954

LOS ANGELES - February 1, 2, 1954

INDUSTRIAL ENGINEERING
IN SMALLER BUSINESS SESSION

Session Chairmen: A. R. Bailey, Berkeley, January 30, 1953
F. W. Cross, Los Angeles, February 3, 1953

THE INDUSTRIAL ENGINEERING FUNCTION IN MEDIUM-SIZED BUSINESS

Stewart M. Lowry
Coordinating Partner, Western Region
Booz, Allen and Hamilton
Management Consultants
San Francisco, California

My assigned subject is "The Industrial Engineering Function in Medium-Sized Business." In the early conversations, the term "small business" was suggested. It might have been just as appropriate. I should have had to treat it in the same way.

Thinking over the subject, I came to the conclusion that an even more **appropriate title** might have been "The Application of Industrial Engineering to Small and Medium-Sized Business." As the title now stands, there may be an implication that there is one kind of Industrial Engineering for big business and another kind for small business. That is not so. Industrial Engineering is Industrial Engineering wherever you find it, just as Electrical Engineering is Electrical Engineering and Mechanical Engineering is Mechanical Engineering wherever you find them. The size of the business may have a bearing on the degree to which any of these, or any other kind of engineering, are needed and used. The difference lies, not in objectives, procedures or techniques, but in breadth and depth of application. The tools are all there for the small business just as they are for the large business, even though they may not be as fully or as comprehensively used.

It may be theoretically correct to say, "Industrial Engineering has proved to be good for big business, therefore, it is good for small business," but any such broad generalization needs some further scrutiny. Big business has been at it for a long time. It has over the years, extended, expanded, deepened and broadened the scope of Industrial Engineering until now it looks formidable indeed to the manager or owner in small business. He knows there must be something in it for him, but is sometimes baffled in how to start -- which parts to accept and which to reject. Let us remember that even big business started off with relatively modest applications. What we see now is the result of years of growth, development and refinement.

Obviously, the proprietor or manager of small business cannot, and should not try to, transplant the Industrial Engineering of big business, with all of its ramifications, into his situation. On the other hand, it is just as wrong for him to close his mind to the applicable practicable benefits of organized Industrial Engineering, saying, "It's okey for General Motors or United States Steel but it's not for me."

Sometimes owners and management of small business think that Industrial Engineering is an overhead luxury which only big business can use and support, but which they, in small business, cannot afford to have. They might, instead, ask themselves, "Can we afford to be without it?" That question has become increasingly important in recent years with the sharp up trend of salaries and wage rates and the costs of raw materials, supplies and services.

My concept of this subject breaks down into two parts which may be identified by two questions.

First, what is Industrial Engineering? In other words, let's examine the kit of tools. Let's review what Industrial Engineering can be expected to do, without regard for the size or complexity of the business to which it may be applied.

Secondly, how can Industrial Engineering be launched effectively and profitably in small and medium-sized business? In other words, what are the essential or minimum requirements to get an organized Industrial Engineering activity started? Then which direction and how far do you go from there?

I hope my approach does not sound too naive, to say, "What is Industrial Engineering?"

Most of you who are practitioners or teachers in the field know as well as I do what it is, both from the theoretical and technical viewpoints as well as in terms of your own individual experience and observation.

Yet, if I were to ask for simple one-sentence definitions from a dozen qualified authorities in this room, I daresay we would get quite a variety of answers. So for purposes of this discussion, I am going to offer an over-simplified definition of my own. "Industrial Engineering is the art, science and practice of setting operating standards and of measuring performance against those standards."

Immediately, you can think of many appropriate qualifications for that definition. I said it was over-simplified. My purpose is to set up a nucleus for our discussion today. My remarks will expand upon but not wander far away from the simple basic concept of setting standards and measuring performance.

Let me explore what we mean by setting standards. In the definition, I used the words "operating standards" because I want to confine this discussion to the operating side of a business as distinguished from sales and distribution, finance and accounting, administration and general office and the like. While Industrial Engineering has application in these latter areas, they do not usually offer the logical starting places.

We might first look, then, at how the physical work of the company is done -- how its operating objectives are accomplished. Are we making the best use of our available facilities -- our property and buildings, our equipment, our manpower? Are these facilities best suited to our needs or should there be some changes -- changes in location, sources of raw material and supplies, receiving and storage, transportation, internal handling, processing or mechanical equipment, layout, quality control, inspection, packaging, warehousing and shipping? The detail problems will differ widely with different industries and different kinds of business. A single-product processing industry such as a saw-mill or a coal mine will differ in the degree of emphasis on the various parts of the problem from a complex chemical processing industry such as a dye works, a soap plant or an oil refinery. A machine shop producing duplicate parts in large quantities will differ from a fabricating job shop, or a foundry, or a steel mill. A wholesale distributor's operating methods differ in many respects from those of a retail store. But regardless of size or type, every business is susceptible to a scientific analysis of its operating methods. Broadly, this aspect of Industrial Engineering is characterized as Methods Engineering. Its objective is to develop the best possible methods with the facilities available, or to justify capital expenditures to secure improved facilities and still better methods. It aims at determining and setting as standards the best operating methods under the various conditions likely to be encountered.

In appraising the relative merits of alternative methods, in his search for a standard, the Industrial Engineer uses various applicable devices and techniques. Favored ones are process and flow charts, layout plans, equipment templates, time study, and where applicable, motion pictures. He is endeavoring to reduce the number of handlings and movements of material in process, to shorten time and distance, to utilize gravity where possible instead of manual, mechanical, electrical or other power, to eliminate unnecessary work, to improve sequence of operations, to utilize capacity of equipment and facilities, to improve yield from raw material and quality of product. In other words, he wants a method that will save material, time and money. These are merely some of the specific approaches to the general problem.

In all industries payroll costs are important. It is always desirable to find ways to make manual or clerical work easier and more effective -- to reduce the direct labor cost per unit of output. This requires standards and to get the standards requires time and motion study in one form or another. Therefore, we cannot get very far in an Industrial Engineering program without one or more competent time study men.

The time study man can do more, however, than merely study manual operations. He can also effectively study machine speeds, capacities and outputs, and correlate manual attention with them when necessary. In some instances machine efficiency is much more important than manual efficiency. Large expensive machines or processing equipment can produce at maximum capacity sometimes only at the expense of an apparent excess of manual attention. The Industrial Engineer will balance these factors.

Tradition may be somewhat to blame for undue association of Industrial Engineering with labor standards and wage incentives. Pioneers in Industrial Engineering directed most of their attention there in the beginning. But in many industries raw material yields, and proper utilization of utilities and supplementary services, identified in our books of account as overhead, are equally or more important. They, too, need standards against which to measure performance and the qualified Industrial Engineer can produce those standards.

It might be said that operating supervisors or staff technicians, other than Industrial Engineers, could also produce those standards, and that would be correct. In many places they do set standards for work under their direction, and use them for control purposes. I am suggesting that the Industrial Engineer is qualified by training and experience to set standards, and if the task is delegated to him he will probably do a better job because it is a major responsibility with him, and he will relieve the operating supervisor of a task that is regarded as secondary responsibility and against which he may not bring the best techniques and ability. At the risk of laboring the point, I want to re-emphasize that one of the major functions of the Industrial Engineer is to set standards -- all kinds of standards -- standards for material usage, for machine output, for processing yields, for usage of supplies, fuel, steam, power, water and the like, all related to units of production or service performed.

Obviously, standards have little value per se. They assume value only when they are used. There are many ways in which they can be used, which I shall discuss presently, but first I want to make the point that their value is limited by their accuracy. The term "standards" can be, and often is, used quite loosely. Sometimes averages of past performance, with or without arbitrary modifications, are regarded as "standards." Such historical standards are seldom adequate because they contain the errors of the past, and under constantly changing conditions, they lose their significance. To be most effective, a standard should represent a difficult but attainable performance under currently prevailing conditions. It should reflect what <u>ought to be</u> accomplished -- not what <u>was</u> accomplished. To secure that type of standard needs the analytical engineering approach -- the approach employed by the qualified Industrial Engineer.

Now, what uses are made of engineered standards? I do not want to leave the impression, because of the chronology of this discussion, that I am advocating turning one or more Industrial Engineers loose in the plant to first build up a great mass of standards and then decide how to use them. Actually, the procedure is quite the reverse. We know the objectives, or at least some of them, before we start to develop standards, and then we develop only those standards that have a direct bearing on the objectives. The reasoning process may go something like this:

> Management becomes concerned about profits.
>
> Disregarding for the moment, opportunities that might lie in the sales area such as greater volume, higher prices, additional products, advertising, sales methods, and the like, management turns to operating costs.
>
> A study of operating costs discloses areas where there appear to be opportunities for savings.
>
> Some of the specific problems might be:
>
> (1) Excessive waste of material -- scrap losses too high -- poor yields -- too much reworking -- damage in handling -- poor quality control -- etc.
>
> (2) Inventories too high or poorly balanced reflecting loose purchasing practice or poor planning generally.
>
> (3) Poor production planning and control, reflecting overloading or underloading of equipment, excessive in-process delays and emergencies resulting in high overtime costs to meet schedules.
>
> (4) High labor costs due to poor planning, inadequate supervision, training and instructions, or simply soldiering and general labor inefficiency.

(5) Excessive overhead costs including wasteful use of utilities and services.
(6) High repair and maintenance costs due to avoidable equipment breakdowns or failures.

Some of the corrective devices that might be applied are:

(1) A sound plan for material control at all points in the process where losses might occur.
(2) An inventory control plan that takes into account the problems of supply, optimum purchasing quantities, favorable prices, production requirements, minimum commitment of working capital and maximum turnover.
(3) A sound plan of production planning and control that keeps work-in-process moving and integrates sales orders with raw material supply, production capacity and shipping schedules.
(4) Incentive plans that stimulate the best efforts of both labor and supervision and relates the amount of compensation to performance.
(5) A preventive maintenance program that anticipates breakdown and repairs to minimize their occurence at critical times.
(6) An overall cost control plan that provides complete simultaneous control over all items of operating cost whether they be for material, labor or overhead.

Management will then decide whether one or more of these devices will be effective. They may set somebody to work on developing specific tailor-made plans for their business.

It would not be until after the specific plans were developed and approved that the work of setting standards necessary for satisfactory applications would begin. Any one or all of the management tools I have mentioned require sound standards to make them work properly. The industrial graveyard is full of plans and systems that failed to work. Many of them died because they were not properly conceived and soundly tested for the specific situation in the first place. They might have been the result of a week-end inspiration by the president who read the success story of another company in a book or magazine and he decided to try it in his own company. But such instances are probably rare, and the implication is not very flattering to presidents as a class. I think they are a lot smarter than that. It is much more likely that death resulted from more insidious diseases, such as half-hearted support from management, or resistance from supervision, staff departments and rank and file because it is human nature to resist change, or it could have been because of poor standards that would not stand up under actual application. When men are having their performance measured against standards in which they have lost faith, they begin to lose faith in the plan or system of which the standards are a part. Another reason that justifies the skill and effort necessary to produce sound standards is that they are to a great extent interchangeable in the various plans I have just mentioned. Standards that are required for a material control plan, a production control plan, an incentive plan, a plan for the control of maintenance, repairs and other overhead costs are generally suitable, or can be readily adapted for a fully integrated over-all cost control plan.

I mentioned before that standards are of little value for their own sake. They are valuable only as measuring sticks against actual performance. However, random or partial application leaves much to be desired. To make them most valuable they must be incorporated into a systematic and comprehensive control plan that automatically brings the actual figures alongside of them, for ready comparison. Thinking of them in such an application, they should meet the following tests:

(1) Standards should represent high level but attainable performance under normal operating conditions.
(2) Standards should generally represent an improvement over past performance, although there can be exceptions.
(3) Standards should be established by the application of modern Industrial Engineering techniques.
(4) Standards should be equitable; 100% performance should represent the same level of achievement in all cases.
(5) Standards should be acceptable to the individual whose performance is to be measured.
(6) Standards should be comprehensive, providing as nearly as possible complete coverage within each area of responsibility.
(7) Standards should be maintained so that they are always a true description and measure of currently prevailing methods and conditions.

Now, how can the small or medium-sized business apply Industrial Engineering as a profitable and effective management tool? Obviously, there is no uniform pattern. Each company must work out its own individual approach. Yet there are some basic principles and ground rules that might be agreed upon at the outset, such as:

(1) There should be agreement that Industrial Engineering <u>is</u> a sound and effective management tool that can be applied profitably to this business.
(2) The first step should be a modest one.
(3) Each step should be taken to satisfy a recognizable need of the business.
(4) The program should "pay its own way."
(5) Competent Industrial Engineering personnel (one or more) will be assigned or engaged for the work as a full-time responsibility.
(6) The program, once launched, will have full management support.

I shall elaborate somewhat on these points.

Industrial Engineering, through its wide acceptance, has demonstrated its usefulness. Most companies with 50 or more employees are probably applying at least some of the principles and techniques, if only informally, whether or not they go by the name of Industrial Engineering. Their recognition for what they are will not reduce, and probably will increase, their effectiveness. A brief objective survey of all operations will disclose the major problem areas -- areas in which improvement is desired. These problems can be identified and defined as separate projects. Priorities can be established according to their importance from the standpoints of needs and savings potentials. They can then be undertaken and solved one at a time.

The first project should be a modest one. It should be one that can be completed and will start paying off in a reasonably short time.

Successive projects should be undertaken in the order of need and economy potentials.

Industrial Engineering has a virtue not found in some other staff functions. Its effects can generally be measured in dollars and cents. It can be installed with the expectation that it will "pay its own way." It generally does, many times over. One of its primary purposes is to reduce and control operating costs. Benefits should be reflected directly on the cost statements.

I have said before that most companies carry on Industrial Engineering practices in some fashion or other without necessarily identifying them as such. Most businesses set standards of various kinds for their operations. Some attempt is usually made, with or without specific standards, toward control of material, labor and overhead. Though it might be rudimentary, one can usually find some type of production planning and scheduling of orders. Often improvised incentive plans are in operation. These activities are generally handled by supervisors or executives, supplementary to their normal routine duties. To form the nucleus of an organized Industrial Engineering function, these functions can be gathered together and made a primary responsibility of a qualified staff specialist. If such a man is not available within the organization he should be employed. It can be started with one man. His program should be determined by the survey previously referred to, of the needs of the business. Its expansion can be controlled as warranted by results and to meet demands for completion of the projects deemed necessary by management.

To be effective, the Industrial Engineering function must be given proper status in the organization. Its objectives, limitations and areas of operation should be defined and understood by everyone concerned. Its reporting relationship should be clearly established, as well as its working relationship with supervision and other staff functions. It might well report to the executive responsible for operations. In a small or medium-sized business this might be the president or general manager. Above all it should have full support from management. As with any new activity, there will be substantial inertia to be overcome before it is firmly established and operating smoothly.

My treatment of this subject has been necessarily quite general. Admittedly, I have oversimplified. There is no hard and fast formula for installing Industrial Engineering in all types of business. Each requires a tailor-made approach but the same basic concepts and principles will always apply.

INDUSTRIAL ENGINEERING, PLANNING AND CONTROL FOR SMALL MANUFACTURING PLANTS

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In attempting a presentation such as this, one is caught at once with the magnitude of the subject matter embraced in the title "Industrial Engineering, Planning and Control in Small Manufacturing Plants". Certainly the subject is especially pertinent here for our local area is predominantly of the small manufacturing plant type. (The latest figure I was able to locate showed an arithmetic mean of 30 production employees per plant in California.) Even with the tremendous expansion of Western manufacturing facilities the proportion of small to large plants probably has not changed appreciably since the start of World War II; and this, in spite of the many large Eastern firms that have found it economically possible to bring to the West Coast very sizeable plants for important segments of their manufacturing operations.

Because this subject deals with some problems and some possible solutions, the discussion will be largely critical of small plant operations. Lest this should be considered a broadside indictment of all of them, I hasten to deny it; and, further, I should like to first of all acknowledge that according to today's standards there are many of these plants who are quietly going about doing a fine job. However, the subject assigned to me deals with plants in various degrees of difficulty and with possible solutions that suggest the use of better industrial engineering, planning and control.

At the outset it may be pertinent to ask "Is there something inherently different between a large and a small plant?" Something really, fundamentally, different? I confess I cannot find any basic difference. But I do not mean to imply that one does not exist just because I have not discovered it. I know that small plants seem different. Those who view the concept of organization in terms of its departmentalized function would perhaps point out that all manufacturing plants require a management span embracing, as a minimum, the areas of merchandising (including market research), engineering (including research and development), general business (including financing, accounting, auditing, credit, and the like), manufacturing (including procurement, etc.), and human relations, plus organization; and with this as a premise, they would marshall solid argument to prove that what appears to be a basic difference between large and small plants is just a matter of emphasis, a matter of degree.

Well, it is not my purpose to settle this controversy nor to build up straw-man arguments just to knock them down. I simply want to be sure we have recognized at the start that harassed small plant management, by and large, takes a dim view of any person saying "What will work for a 5,000-man plant will work for a 50-man plant if the principles are not violated." Small plant managers -- at least, a substantial number of them--simply are not impressed by such statements and honestly do not believe this to be the case.

Going just a step further in this preface, it may well be that the reason for the types of difficulties experienced by many small manufacturing plants is that the owner is also the manager and that may not be good. For it seems a pattern of many small plants that the owner-manager is relatively strong in one or two of the six functions I have enumerated (merchandising, engineering, general business manufacturing, and human relations, plus organization) and is correspondingly weak in the balance of them. When the weakness includes that of organization, then many of the difficulties that I am about to discuss will quickly become apparent and, what also appears to be a pattern, the resulting type of company structure usually has no strong personnel within it to compensate for the weakness of the owner-manager. Still another pattern is that this owner-manager feels that he is competent in all functions of management (probably because he is so very competent in one or two of them) and therefore is not aware of the very real danger he faces in not properly "touching all the bases.

* * *

But now to get to the practical matter at hand. What can we say regarding the specific situation of the small manufacturing plant in terms of Industrial Engineering Planning and Control:

First, there is a great need for PLANNING as a routine management technique. Now planning, to be successful, must have underlying it a philosophical point-of-view by management that makes it an important technique in the whole plant organization. If the small manufacturing plant can acquire such a point-of-view, certain things will happen that not only will be important on the management level but will immediately focus attention to those aspects in the plant that are peculiarly the function of industrial engineering*. It will establish an organizational structure if one has not already been established. (This very important point, with its implication of organization planning and control, I will reluctantly leave out of this presentation in order to concentrate closer to the "firing line".) Also, and very important, adequate technical information will be required. This may sound almost trite, but it has been my personal observation that by and large a lack of technical adequacy is one of the big differences between small-plant and large-plant manufacturing. This is a matter of degree, of course, but all too frequently it is apparent that the small plant management has not comprehended the extreme importance of technical accuracy all through the engineering and manufacturing operations. As as consequence of this oversight, many difficulties arise, some of which have very serious consequences.

I am thinking of a case of a small plant manufacturer who successfully got into the market on a very saleable product and in a relatively short period of time was doing rather well. In the inevitable course of things he saw where improvements could be made here and there and, because he was technically minded (the inventor type) and was close to the manufacturing situation, he personally added these improvements from time to time. An Engineering Department was not necessary in his opinion because the plant was too small. All he needed, he said, was "someone to make the drawings". In these earlier days there was a direct management-production relationship and it got along fine. Whatever changes came along were sketched

* "Industrial Engineering" in its broadest definition here.

out in the shop and were tested by placing them in units sold to customers close enough to the plants to allow reasonable observation of results. Now this was a good product, the improvements were by-and-large good improvements, and in the space of a very few years the company had achieved an international reputation and the plant facilities had correspondingly expanded. So far so good.

But the attrition that comes with time was taking its toll and soon the original customers began to order parts replacements for the product. Parts that were supposed to be correct were sent out but the customers wrote back "No". That stumped the order department and in subsequent correspondence with the customers it appeared that there was no correlation with the old records (such as they were) of parts used and what the customer claimed he had.

So the manager (who now was no longer close to the manufacturing problem) had to round up those persons who were still present from the "old days" in order to get suggestions as to what might be in the field units. In subsequent bull sessions it developed that any one of several possibilities existed. So the company was finally forced to write to the customers and explain that a drawing of the parts would be required if it was not convenient to send the original pieces themselves. As time went on the company was deluged with this sort of thing until it finally had to stock just about every version of every perishable item that any kind of record indicated had previously been made. I am told that this decision resulted in extra inventory of approximately $250,000.00.

Now I have spent this amount of time relating a single true incident because it portrays what can happen to many small plants that are treading paths equally dangerous by ignoring the requirements of technical accuracy in the pre-production as well as production stages. Actually many of these plants are in such bad shape in this regard that any large scale success might almost be their undoing, for to their customers they are selling products the nature of which is that replacement of parts will be inevitable, yet practically no provision is being made to correlate the design with serial numbers or other identification media, to record historically the transition of changes in design, or any number of other things that will have to be faced in the natural order of things. For example--and I have seen this happen very often--they may be changing tools which make the parts and they may be making no provision to record the tool changes in relation to part changes. Or they may be changing inspection equipment such as gauges and are not providing the historical correlation needed always to control the quality of parts rerun from old designs. They may be failing to record technical processes whereby certain components of the product are created, may be neglecting the need for specifications to control either their own or sub-contractors products, may be overlooking the need for such a thing as blueprint control. Likewise, there may be no recognition of the necessity to provide adequate parts numbers or to maintain adequate parts lists or bills of material. The long look toward the ultimate requirement of standard may not even be considered.

In short, the management may have lost sight of the fact that a management-production relationship in present day small plant manufacturing is not enough even when the head man is pretty good in these two fields. On the contrary, management-<u>engineering</u>-production teamwork of the healthiest sort must truly exist even in the smallest plants. And here may I say by way of parenthesis that I would reiterate <u>even in the smallest plants</u>. There is absolutely no reason to believe that any technical function in a manufacturing business, which is required for long term success for a large plant, can be ignored in a small plant. To cite a homely analogy, certain things are vital for continuity of human life and among these are food, water, oxygen, and the like. Just so, there are certain things that are vital for the continuity of any manufacturing plant of whatever size. And it is the purpose here to try to stress that when any plant, small or large, violates the minima that are required for continuity, this self-imposed industrial malnutrition will inevitably yield rather grim results.

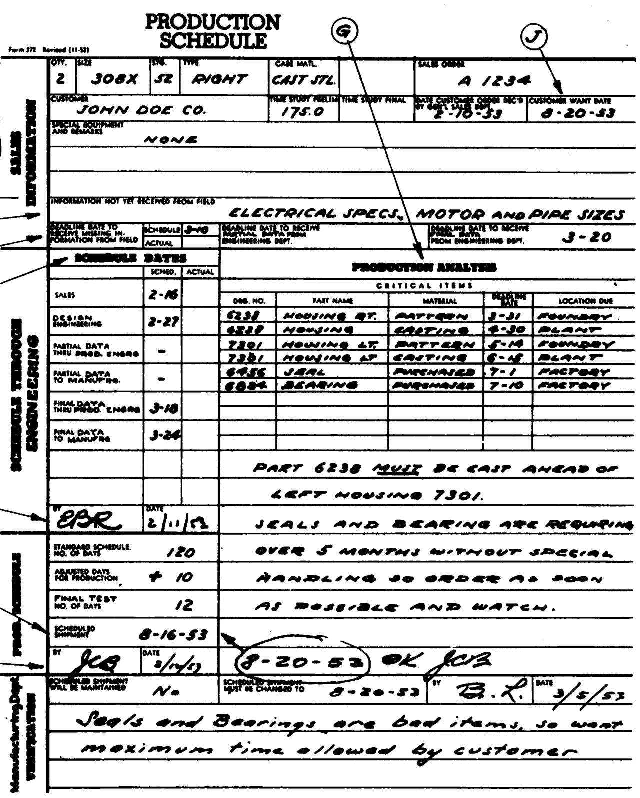
The practical question arises as to whether or not it is possible to ignore the engineering function in a small manufacturing plant. The answer seems to be quite apparent. It is that no plant can get along without this function, whether it be done in a very small plant by one man on a part-time basis or, if the economics and conditions of the plant and process warrant it, by many men on a full-time basis. The point is that it just is not possible to go below the minimum requirements of present day manufacturing so far as technical accuracy is concerned and still expect long-haul to remain in business.

Another point here is that the minima are changing just as standards of living are changing. Twenty-five years ago the competition was such that some pretty indifferent standards of acceptable technical minima could get by. This was only because it was the way things were being done in other places. Today, competition and consumer demands being what they are, all this is changing. And we can hope that in the not too distant future the concept of Industrial Engineering, in some of its more advanced aspects, will be found in the minima accepted for even small manufacturing plants. Today, however, we are not in that position and it is, of course, the reason we are here discussing the subject. I believe that a paper on the subject of 'The Complete Engineering Function in a Manufacturing Business' would be a significant contribution to the advancement of engineering in education and in practice, and would be a pertinent subject for an Institute such as this.

<u>The next major point is that CONTROL, which should be an indispensable tool of small plant management, is considered by many of them to be still something of a luxury and something that only big plants can afford</u>. Some time ago the manager of a well-known local plant said to me, "When I think of the small amount of information I have available to help me make up my mind, it scares the hell out of me". Yet while control departments were set up in his program (at least, that's what the signs on the doors said) the Philosophy of Control as a working, dynamic concept was missing. It is no wonder that this plant and its creditors had strained relations.

On the matter of meeting the delivery dates, many small plants are harassed by this problem and particularly the manufacturing departments are in difficulty usually because of any of four reasons: (1) The technical information required to manufacture the product is made available to them so tardily that setting up any type of manufacturing program within the time allowed is out of the question. (2) The pre-planning of manufacturing operations and the coordination and control of them, is inadequate. (3) The coordination of concurrent operations or functions--purchasing, tooling, inspection, and the like--also is not adequate. (4) Technical accuracy is not adequate. It is indeed difficult for some departments in a manufacturing business to recognize that, once an order is received, they are service organizations to the Production Department.

To cite an example of the first point in the previous paragraph, a certain plant found itself with increasing orders of not inconsiderable size. These increased orders were taken with a delivery date in mind that seemed perfectly possible at the time the orders were received. However, it soon became apparent that the elapsed time from receipt of order to final shipment was getting longer and longer. The question was, what to do? The production department claimed that the engineering department took too long to get the specifications to it and consequently the production side was in no position to meet impossible delivery dates. The engineering department claimed that the sales department frequently did not provide information soon enough to complete the technical requirements in time to meet the delivery date set up by the sales department in the first place, on the basis of customer need. Both departments, engineering and production, felt they were being pushed beyond what could be expected of them and perhaps the logical approach from their point-of-view would have been to extend the delivery date. But that was not possible because the sales department, while admitting its fair share of responsibility, was sensitive to the fact that competition, coming from bigger plants, required even faster deliveries than were currently possible. Consequently, the realism of this situation forced a focusing of attention to the roots of the difficulty. Figure 1 shows the result of considerable analysis on the part of that company's management, sales, engineering, and production departments, an analysis which uses a solid industrial engineering technique for grappling with the problem.



Upon receipt of the customer order, the Sales Department fills out the section bracketed by A, and forwards the Production Schedule sheet on to the Production Scheduler who assigns practical deadline dates for the receipt of the necessary field information (of line B) and posts these dates on line C. The Production Schedule sheet then goes to the Production Engineering Scheduler who has the responsibility of scheduling (in cooperation with the departments involved) all items shown under "Schedule Dates (Through Engineering)" D. He signs the Schedule at E and returns it to the Production Scheduler who proceeds to make an analysis of the manufacturing problems to the extent of establishing a tentative scheduled shipment at F. This study includes a Production Analysis G which seeks to establish those critical items that will influence the delivery date. The Production Scheduler then signs the sheet at H and sends it to the Manufacturing Department for acceptance or rejection. Should the Manufacturing Department refuse to accept these dates it can "carry its case" to the General Manager (as any other department that finds a schedule unacceptable). No date later than that given in the "Customer Want Date" box J is permissable without its acceptance by the customer.

FIGURE 1. SCHEDULING JOB FROM RECEIPT OF SALES ORDER TO SHIPPING DATE

The importance here is not the specific solution but rather the technique employed. Here was a case of a small plant that had a major problem and whose approach to the solution of that problem was reasonable. If all other aspects of the management-sales-engineering-production relationship are tackled on the same basis, there seems little doubt that this plant, although competing with more sizeable ones, will be able to successfully hold its own and to even improve its position.

But of course delivery dates cannot be achieved simply by a piece of paper such as a master schedule sheet shown on Figure 1. Instead, that brings us to the second point that the careful analysis of all phases of manufacturing operations must be made and control must be established each step of the way to insure that a manufacturing schedule, once established, will be maintained. Again this is done in most large plants as a routine necessity, yet many small plants operate on the assumption that production control on a rather "tight" basis also is a luxury. Let us see. Figure 2 shows the basic control mechanism of a plant employing approximately one hundred direct labor employees and which can maintain a very tight schedule control over its operations.

ROUTING (OPERATIONS) SHEET

JOB No. 1832-2
PART No. 3 REVISION C DATE 3/12/53
MATERIAL $2\frac{1}{2}$ RD. C.R.S. BY A.L.K.

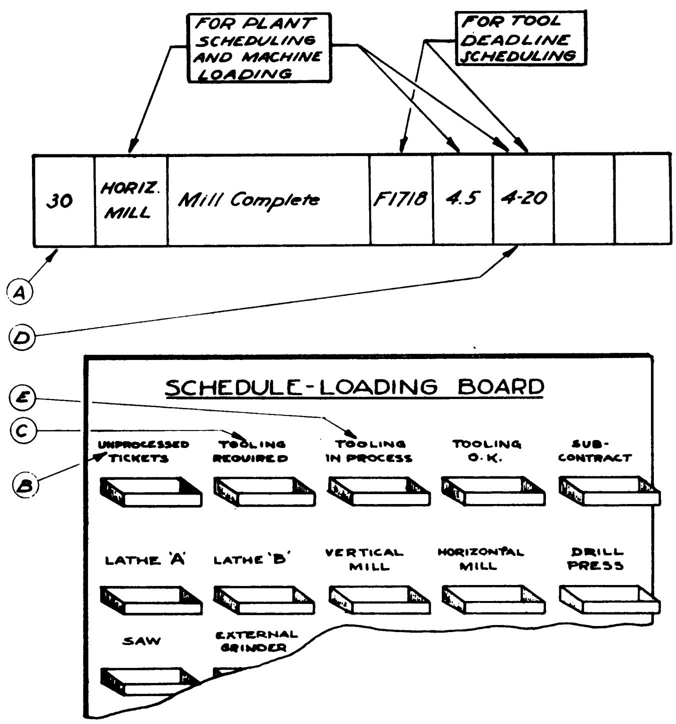
OPER No.	OPER. NAME	DESCRIPTION	TOOL REQ.	EST. HRS.	DATE DUE	INSPECT O.K.
10	SAW	Cut to $12\frac{5}{8}\ {}^{+\frac{1}{8}}_{-0}$		1.0	4-9	
20	LATHE A	Finish all over except bearing diameters Make them $^{1.810}_{1.800}$ Note class 3 threads	G 162 G 163	14.0	4-13	
30	HORIZ. MILL	Mill Complete	F 1718	4.5	4-20	
40	INSPECT	Check Milling Contours	G 1719	-	4-21	
50	DRILL PRESS	Drill all holes	J 1720	3.5	4-27	
60	EXTERNAL GRINDER	Finish Bearing Dias. to size		2.0	4-29	
70	STORES	To Subassembly Stores for Assy. 2678		-	4-30	

FIGURE 2. ROUTING (OPERATIONS) SHEET

Again, this is not being shown to illustrate the exact arrangement that should be used in every plant, but rather it highlights the simple type of operation sheet that can be used in very small plants, considerably smaller even than the plant to which I referred. Operation sheets, of course, are not new. And many small plants use them or their equivalent. So it may be that some in the audience may be wondering why I "waste time with old stuff" and wish me to launch boldly into such things as "The Application of Standard Data to Small Manufacturing Plants, etc." The answer to that is simple: The small plants that are in difficulties, production-wise, are largely back in the under-graduate condition I am discussing. They will not be able to accept the graduate level work until they have progressed much farther along the way.

The question might be asked, How could this Routing Sheet be expedited to be sure that things were going as planned? One answer might be in having an arrangement as shown in Figure 2b.

A major point should be made here which is this: Every single item shown on the Routing Sheet of Figure 2 is nothing more than the simple recording of a decision. The total sheet is the result of a whole series of decisions: How the operations are to be performed in what sequence, what kind of tooling is to be employed, what date each step of the operation is to be performed, etc. Now, whether the plant is run at the very maximum of efficiency--using the very best techniques of industrial engineering, planning and control--or whether it is the sloppiest plant in the area using no operation sheets at all, EVERY SINGLE ONE OF THESE ITEMS HAS TO BE DECIDED UPON. It isn't a question of short-cutting decisions, for they have to be made in either case. Obviously the use of the Routing Sheet requires that some one competent to make it will accomplish this task in advance of production. The nature of the form requires that he give consideration to those essentials that establish the minimum requirements for planning, and in ample time ahead of actual operations to reduce the time pressure that usually leads to decisions based on expedience rather than considered judgment. For in the poorly planned small plant, the best management



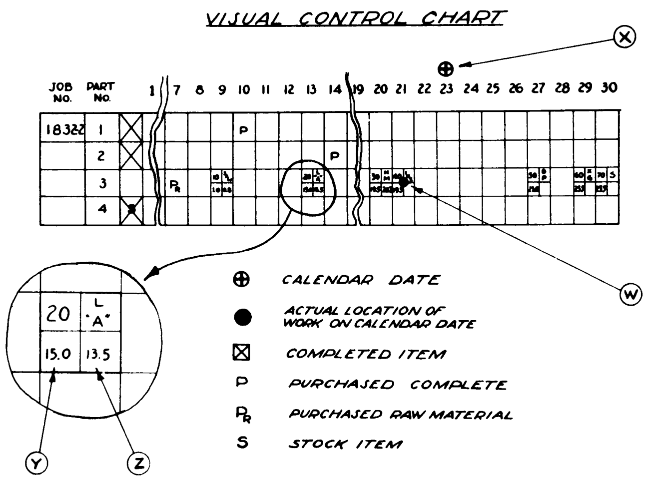
Assuming the Operations Sheet (Figure 2) is made in duplicate, the second copy can be separated by operations as indicated above at A. These "unprocessed tickets" are then dropped in box B from which they are distributed to their appropriate other boxes. If they require no additional tooling, they are placed in the box corresponding to their operation name (in this illustration it is "Horizontal Mill") and can be scheduled based on completion date D.

If tooling is required, then the card will be placed in the "Tooling Required" box C. The person responsible for tooling scheduling will process these cards in order of priority established by completion date D. When the tooling is being worked on, the card will be in the "Tooling in Process" box E, and when it is completed it will be placed in the "Tooling O.K." box and subsequently, in the correct "operation name" box. (In actual practice, a colored duplicate is immediately placed in the appropriate "operation name" box for scheduling purposes while the regular card proceeds through the tooling program as described above. This allows scheduling to be done while at the same time the colored ticket indicates that tooling completion is required before the specific operation can get under way. This tends to expedite the tooling. The same procedure is used if subcontracting is employed.)

FIGURE 2b. SCHEDULE-LOADING BOARD

talents are directed at getting out of trouble rather than staying out of it. A Routing Sheet is a technique for reversing this.

Another answer might be in having a visual control such as is shown in Figure 3. This is a control both for delivery date and direct labor cost.



The object of this Visual Control Chart is to present the current situation of each Part both with regard to (1) actual status in relation to scheduled delivery and (2) actual status in relation to estimated direct labor cost.

So far as scheduled delivery control is concerned, this chart is no different in essentials from many others. It simply records daily the location of the work W for comparison with the actual calendar date X. However, with regard to direct labor cost control, this chart has some unique features. The estimated time is posted in the lower left hand corner of the box for each operation cumulatively at Y. (The posting time for this example is taken from the data in Figure 2; with the material data taken from Figure 6. It also assumes adequate time card control, and hence good direct labor basic cost data, such as is suggested in Figure 5.) Then, as the Part progresses through it cycle, actual time is posted in the lower right hand corner of the block at Z, also cumulatively, after each operation is completed. Consequently, it is possible to see on the one chart how each item of each job is progressing both with respect to (1) delivery date and (2) cost. Since this visual control can be prepared on duplicated sheets, it is not costly to set up yet it yields the basic information that is essential for good control of small operation-type manufacturing plants.

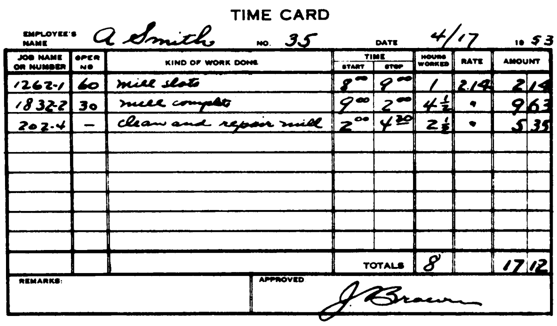
FIGURE 3. VISUAL CHART FOR CONTROL OF DELIVERY DATE AND DIRECT LABOR COST

It is difficult to make a major point of the importance of this without being sure that bench marks have been established. As I see it, viewing the manufacturing aspect of the plant solely, it performs its functions if it meets these two requirements: (1) it does work of acceptable quality on time, and (2) it does this work within the cost* allowed. This goes for any plant of any size. Large plants establish rather elaborate controls to insure that these conditions will be met. A point I am trying to make here is that it would cost no more to install an adequate system for a small plant than it would cost to have no system at all. For no system at all costs real money and basic controls are not luxuries.

Now, with regard to cost control, this is a matter that perplexes many small plants who use rather archaic methods of handling time cards and material control cards, (if, indeed, any are used at all) and consequently the cost data are relatively inaccurate and therefore dangerous to employ when estimating future work. Here again poor cost information places small plants at a decided disadvantage when competing against larger plants in a tight market. Indeed, there is adequate information to believe that this is a major source of difficulty for small plants. Consequently, a little time spent on this subject would certainly be in order.

Figure 4 shows a conventional time card such as is used in many small plants. In it the worker, whose direct labor it is supposed to record, makes out the time card. And, at

* The specific illustration to follow will deal with direct labor cost only. The control of indirect manufacturing cost is not included, except indirectly by examples, in this paper.



TIME CARD

EMPLOYEE'S NAME a Smith NO. 35 DATE 4/17 19 53

JOB NAME OR NUMBER	OPER NO	KIND OF WORK DONE	TIME START	TIME STOP	HOURS WORKED	RATE	AMOUNT
1262-1	60	mill slots	8⁰⁰	9⁰⁰	1	2.14	2 14
1832-2	30	mill complete	9⁰⁰	2⁰⁰	4½	•	9 63
202-4	—	clean and repair mill	2⁰⁰	4³⁰	2½	•	5 35
				TOTALS	8		17 12

REMARKS: APPROVED J. Brown

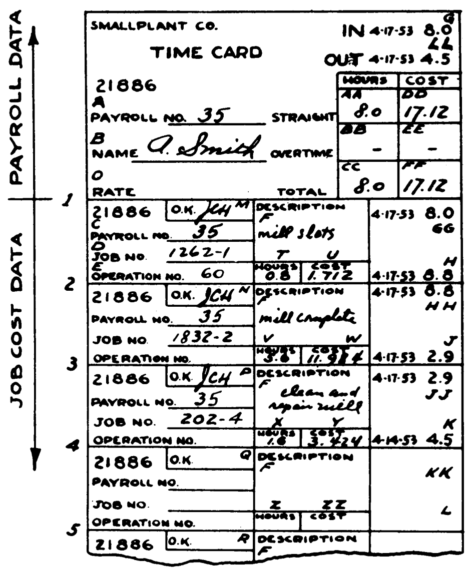
FIGURE 4.

the end of the day, it is audited by the foreman, signed by him, and is then sent directly to the cost-payroll department for posting against the job order. Anyone who has had experience with this type of time card knows the arguments against its use. Certainly these arguments are serious enough to make it quite apparent that only inaccurate time data, and consequently cost data, can come from such a procedure. For while it is true that the worker is supposed to record each job at the time he starts it and at the time he completes it, conventional practice is that he does not do this until the end of the day. Then he tries to think back as to what he did during that period of time, makes whatever distribution seems to him "reasonable" (including "adjustments"), and he then passes the completed card on to the foreman who is supposed to remember how this man and every other man in his department worked, so far as time is concerned, throughout the whole day. This being an impossibility, he generally signs it quickly (because he wants to get home, too), and it is in this condition that the time card goes to the cost department for whatever extensions are necessary in order to figure the job costs.

To illustrate an improved procedure for a small plant, Figure 5 shows another type of time card. This card, or one very similar to it, has been successfully employed in both large plants and small and will record faithfully, if proper procedures are employed, a much more accurate time that has been used for each operation. What is important here is not only each step has been properly recorded and audited as it occurs, but the payroll data and cost data are in balance at all times. Even more pertinent to the specific subject under discussion here, it is possible to separate these cards out by job order and by operations and to assemble them thereby, so that no posting to cost journals is necessary except perhaps as a total when the job is closed out. This is a major point for it eliminates considerable clerical time that would otherwise be required. Hence, it can be seen that the time card shown on Figure 4 is expensive if total cost, including the cost of time posting, is included.

But the advantage of this system suggested in Figure 5 is not alone for purposes of time control. Actually, this type of card can be used for production control and as a double check for time control, thus making a very adequate set-up to facilitate both types of control in a small plant.

I will illustrate this by telling of an actual case that caused this type of card to be used in a plant. The time card shown in Figure No. 4 was used in this plant for some time and was known to be inaccurate in result. Just how inaccurate, however, had not been checked. When it was decided to employ a new type cost control system, it was felt that this would have to be "sold" to the men in the plant as well as their supervisors, and it appeared that perhaps the best way would be to determine just how inaccurate the current time card system was. So, without any shop personnel knowing about it, a very accurate check of just what was going on in the shop was maintained for about a week. These results were compared daily with the actual time cards that were sent in to the cost department. The result was that over 90% of the cards had at least one error on them that affected cost, yet which could not be detected by the cost department. Many of these errors were such that even a new time card would not have "caught" them unless the card was audited before it went to the cost department by a person who understood intimately the shop operations then in progress. So it was decided to route the completed time cards through the production control department for



Filled in by employee A B C D E F
Clocked by employee G GG H HH J JJ K KK L LL
O.K. by supervisor M N P Q R
Filled in by Control Dept next day O T U V W X Y Z ZZ
Filled in by Payroll Dept. next day AA BB CC DD EE FF

At the beginning of each shift the employee will clock in on a new card at G (for beginning of payroll time) and likewise at GG (for beginning of job cost time). Commercial time clocks are available for this type of control. The employee will then report to his supervisor for his first assignment which, when received, will allow him to fill out in the first job section his payroll number C, the job number D of the assignment, and the specific operation number E on which he is working. Previously, of course, the employee will have filled in his payroll number at A and name at B.

When the first assignment is completed the employee will obtain verbal approval to clock out and this he will do at H. Immediately he will also clock in at HH, thus anticipating his second assignment and allowing no time to elapse between the first and second jobs so far as time card is concerned.

When he reports to the supervisor for the second assignment, however, the supervisor will check all entries made on the job section of the first assignment to verify that these entries are correct. When satisfied, the supervisor will approve the closing of the first assignment by initialling at M.

This procedure is followed for each assignment until the end of the shift, at which time the employee clocks out at L (for ending of job cost time) and at LL (for ending of payroll time). Thus payroll time and job time should always be in agreement.

It is recommended that the Production Control department (or some responsible person who understands shop operations) double-check the cards when the shift has been completed, for experience has shown this extra check practically assures a perfect time card audit. Whoever handles the Time Control (checking estimated vs. actual time) would verify that on all cards both G and GG, as well as L and LL, were identical. This done, the card could be severered at line 1 and the upper part could be sent to the Payroll department.

The Time Control personnel would post hours at T, V, X and Z, and would also post the calculated cost at U, W, Y and ZZ. Then the cards would be further severed along lines 2, 3, 4, 5, etc., to facilitate grouping by job number and operation number to post to the Time Control master records.

These cards would then be forwarded to the Cost department where they would be filed by job number and operation number.

FIGURE 5. CONSOLIDATING, TIME, PAYROLL AND COST DATA ON ONE TIME CARD

final auditing and thence to the cost department. By this system it was possible to reduce the errors to a negligible amount. But as an important by-product, when the system was finally hammered out these cards were used as double checks as to the exact location of parts in process and wherever there were discrepancies between the production control records and the time card records, then the production control personnel had to verify the exact location of the material before posting to a visual control board. I think it is apparent that this relatively simple time card justified its integrating into the control system as a working member of the control team.

As a final point here, it might be of interest to know that for this whole system of planning routing sheets, handling production controls, and auditing time cards only three persons were required for a plant of about 100 direct labor employees. This staff was able to present a detailed work-in-process report to the plant manager, by each operation of each part, every morning at 10 A. M., just two hours after the close of the previous day's 24-hour, 3-shift cycle. It was also possible to give each department head a summary of estimated vs actual times for each operation performed under his supervision the previous day. I suppose it is anticlimactic to say that under such an arrangement the plant manager became more of a manager and less of a "fireman".

I have mentioned time control and there remains material or inventory control. This is frequently a headache to small plants, but should not necessarily be so. A couple of illustrations may suffice to at least indicate the type of program that may be used here without getting too fancy and running up indirect costs. I have pointed out the need for acceptable minima for technical accuracy. I think it can be fairly stated that no matter what kind of operation-type plant is involved, the engineering for the product should be such that a bill of material should be available with sufficient part numbers and material information. An illustration of this in its simplest form is shown in Figure 6.

JOB NO. 1832-2
DRWG. NO. A 12710
REVISION NO. E
DATE 3-4-53

BILL OF MATERIAL

PART NO.	QUAN.	DESCRIPTION	✓	ORDER	REMARKS	PRICE
1	24	3/8-16 x 1 1/4 STEEL HEX. HD CAP SC.		16205		
2	48	1/2-13 x 1 1/2 DITTO		16205		
3	13 FT	2 1/2 RD. C1018 Cold Dr. Stl.		SEE SUBST.		
4	24	3/8-16 Steel Hex Semi F Nut		S		

SUBSTITUTIONS

3	13 FT	2 5/8 RD		16220		

SHEET NO. 1
NO. OF SHEETS 1
CHECKED BY [illegible]

FIGURE 6. BILL OF MATERIAL

STORES REQUISITION No. ______

QUAN.	PART No.	DESCRIPTION	CHG. TO	STORES BALANCE
	(OPTIONAL)			
REQUISITIONED BY	RECEIVED BY		ISSUED BY	DATE

FIGURE 7. STORES REQUISITION WITH "STORES BALANCE" INCLUDED

Figure 7 shows a very simple Stores Requisition card. I have included it because it has a story behind it that illustrates a problem encountered in one plant. In this particular plant the original arrangement did not include the little box shown in the right hand colum which shows "Balance in Stores". This particular plant had considerable difficulty in reconciling the Inventory Control records which were maintained in the Production Control Department with the actual inventory as was then in existence in the stores bins. All too frequently the Production Control Department had many thousands of pieces in their records but unfortunately the equivalent pieces were not in the bins, and this tended to not only hold up production but also the blood-pressure of the management. The criticism was, of course, directed toward the Production Control Department. But this was not warranted because the Production Control Department was only dealing with records of withdrawals from another department over which it had no control, namely the Stores Department. Unfortunately, the stores requisition card did not have this box in the right hand column. Consequently, there was no way of reconciling the stores actual count with the inventory control count as recorded on the production control records, and from which records new supplies were ordered. The simple addition of this little part on the card made it possible to audit both records, and where discrepancies occured, to bring them into line. This seems like a simple thing, but it was not simple in this plant which, from top management down to the "lowest" production clerk, was pretty much frustrated by this particular problem.

The solution actually came from another plant long "control conscious" that had long used this particular extra step. It really was no "extra" step at all for it is the logical development for the flow of information from one department to another when it is vital for smooth flow, organization-wise.

This leads to a major point. The concept of FLOW is just as important in small plants as it is in big plants but all too frequently, neither the concept of flow in terms of tangibles (which can be seen in plant layout and things of that type), nor the concept of it in intangibles (such as the design of paper work), is realistically approached in these small plants. Consequently, in some of them there is considerable confusion and frustration and again the management tends to regard any suggestion at major overhaul of procedures as being something that cannot be afforded when, as a matter of fact, it is absolutely essential that this be done in order to maintain any sort of competitive situation, to say nothing of peace of mind. I will develop that point after making this final observation with regard to inventory control. I know of a case of a plant where an assembly line had to be fed with parts each day and the feeding was from parts withdrawn from stores. The withdrawal operation required four persons. A superficial analysis of the percentage of storeroom personnel to the total personnel showed that, while somewhat high, it was not too expensive and it might well have been that this situation could have been allowed to exist. However, an additional analysis was made strictly on good industrial engineering procedure and as a result it was found that the amount of material being issued varied widely from day to day. This did not make sense because it was quite possible to know exactly how many individual pieces would be required on this assembly line the following day by simple advance planning. This having been decided, it was found that the parts could be issued in simple multiples, and as a result all parts were placed in bags when they were originally counted rather than being allowed to be placed in pans in bulk.

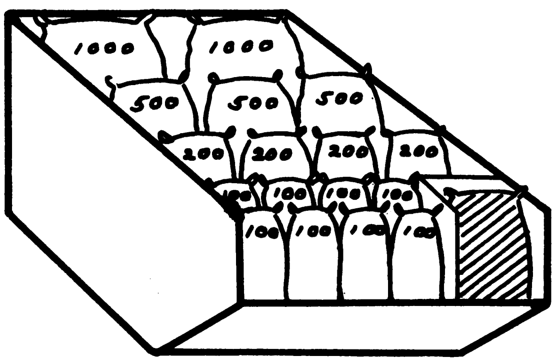


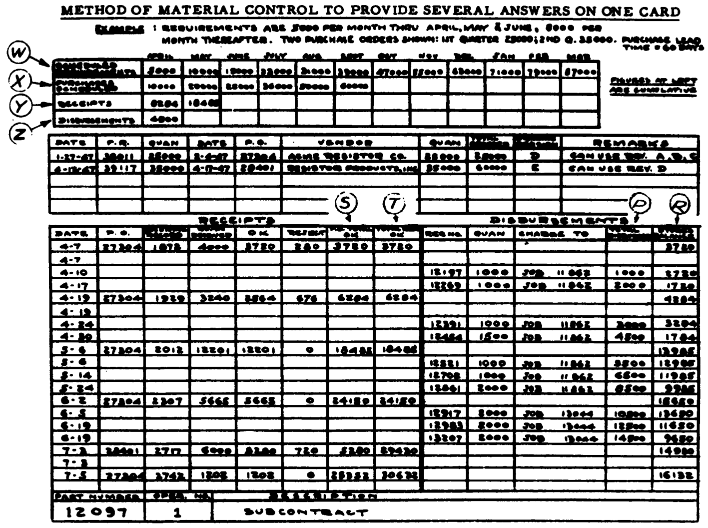
FIGURE 7a. USE OF BAGS TO FACILITATE MATERIAL CONTROL

The parts in the bags were assembled in multiples of 100, 200, 500, and 1,000 as shown in Figure 7a. Actually it took very little extra time to put the parts in the bags, but this eliminated the slow counting of parts at withdrawal time. When this had been done it was possible to reduce the time in the storeroom so markedly that whereas it took four persons to get the material ready for the assembly line prior to the inception of this program, afterwards only one person was required to do the job. As this procedure improved it was possible to eliminate all personnel from the storeroom except one person who was able to handle all incoming and outgoing material, keep stock, keep records, and do the whole job. This again illustrates the possibilities that are inherent in small plant planning and control in the analysis of the day-to-day problems with the view in mind of doing something about them. I would venture to guess that this particular plant's inventory control was among the very best, irrespective of plant size, and yet the actual requirements for the control were very nominal based on essentially sound industrial engineering principles of planning and control.

Figure 8 shows the system that was used for receipt of material. This again illustrates how paperwork flow can be used successfully. If paperwork flow is being achieved, then a somewhat more elaborate inventory control card might be contemplated such as is shown in Figure No. 7b. This card was used in the plant referred to above.

I referred previously to the use of concept of flow in tangibles in a plant. Obviously anyone who has an Industrial Engineering background is thoroughly aware of the importance of flow within the plant and the need of Process Flow Charts or Flow Process Charts or layout models and

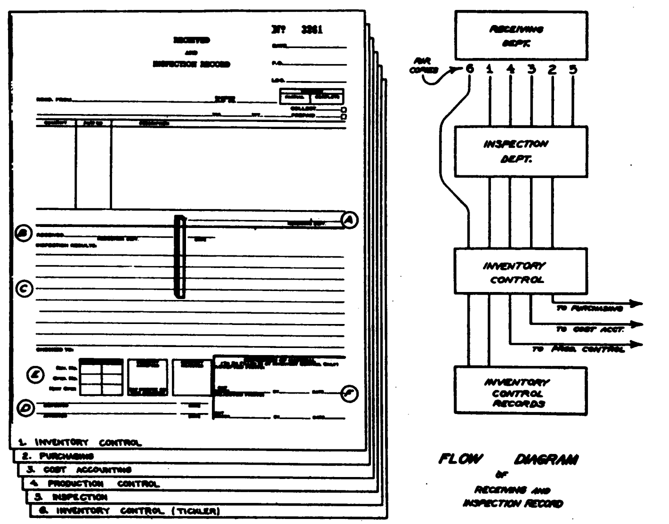
METHOD OF MATERIAL CONTROL TO PROVIDE SEVERAL ANSWERS ON ONE CARD



This will provide perpetual book inventory; specifically:

1. Shows OK material received for each Job Order or Purchase Order (Col. S)
2. Shows total OK material received (Col. T)
3. Assures management adequate purchase or job order control (Col. W,X,Y,Z)
4. Compares actual OK receivals with Purchase Order (or Job Order) requirements. (Col. S vs. Col. X)
5. Requires that schedules be established. (Col. W)
6. Provides monthly analysis of receipts against vendor (or own shop's) promises of good parts. (Col. X vs. Col. Y)
7. Provides monthly analysis of disbursements against receipts (Col. Z vs. Col. Y)
8. Provides monthly analysis of disbursements against scheduled requirements (Col. Z vs Col. W)
9. Provides method of building theoretical lead time (Col. X minus Col. W) yet controlling actual lead time (Col. Y minus Col. Z). This is another way of saying that control is provided for inventory cash investment.
10. Provides stores balance at all times. (Col. R)
11. Provides method of checking possible posting errors since Col. P plus Col. R equal Col. T.
12. By posting rejects (this is optional) it also shows % of rejects in comparison with total receivals. This gives quality status of vendor or own shop at each operation.

FIGURE 7b.



EXPLANATION OF THE RECEIVED AND INSPECTION RECORD

The Receiving and Inspection Record (hereafter called the RIR) is prepared for each kind of material received. It is designed to be used with material received from either outside sources or inside departments.

The Receiving Department fills out the RIR for the items above A and signs at that point, turning all copies of the RIR and the material over to the Inspection Department who signs as acknowledgement of receipt at B and who immediately sends on to the Inventory Control Department the Number 6 copy which automatically provides notification that the material is at inspection.

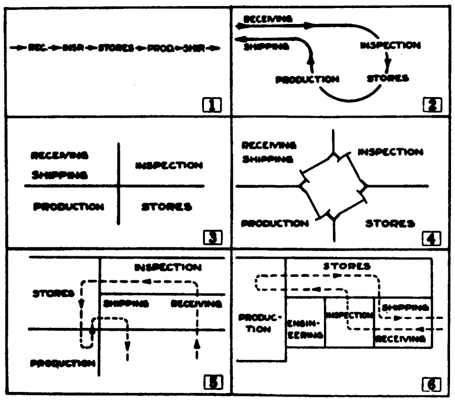
When inspection has been completed the results are recorded at C, and the Inspection Department also posts all pertinent information regarding Accepts and Rejects (in the lower left corner of the RIR) and signs at D. The Number 5 copy is retained by the Inspection Department as a permanent record.

The material and RIR copies 1, 2, 3, and 4 proceed together to the Stores which is under the jurisdiction of the Inventory Control Department. Here the Accepts and Rejects are sent to the station prescribed by the Inspection Department at E and the paperwork covering the disposition of the material on this basis is recorded at F. (If the inventory cards are also posted at this moment, the inventory control should always be current.)

After completing the above, the Inventory Control Department will forward the Number 2, 3 and 4 copies to Purchasing (who clears to Accounts Payable), Cost Accounting, and Production Control (if this department requires the information).

FIGURE 8. RECEIVED-AND-INSPECTION RECORD

all that goes with them in order to facilitate this very important phase of planning-industrial engineering. I thought it might be of interest to illustrate this for small plants in the manner shown in Figure 9.



• Assuming the conventional one-story factory flow requirements of Receiving, Inspection, Stores, Production and Shipping, it can be theoretically set up as at 1.

• In the smaller plant which requires a combination of functions, the receiving and shipping departments usually are required to be together. This can be accomplished without affecting the principle of FLOW by the simple illustration at 2.

• Now, to departmentalize these, it is only necessary to partition them as in 3.

• So a functional working arrangement could take this practical form at 4, wherein each department is separated, but easy access is effected (with consequent great potential gain due to reduction in Material Handling distances and criss-crossing).

• Typical small plant layouts that have actually employed this principle are illustrated at 5 and 6.

FIGURE 9. PLANT LAYOUTS BASED ON THE PRINCIPLE OF FLOW

This, for lack of time, concludes the treatment that I shall give the subject matter assigned to me with the exception of one final observation that I think is pertinent. It is a premise, a statement of my belief, that small plants have three inherent advantages over large plants (my reason for advancing this here is that I have constantly implied that there were inherent advantages in big plants over small plants, and here is a case where I believe the reverse is true). These advantages are:

1. Lines of communication are necessarily shorter in the small plant and this allows for potentially greater management personal effectiveness. This point could be developed in detail but I think it is quite apparent. That is, it is apparent to students of organization. The question is, is it apparent to small plant management? I don't think it is. I do not think that, by and large, small plant management is aware of the tremendous advantage that goes with shorter lines of communication. For, of course, this is no advantage at all if it is dissipated in lack of planning and lack of control. But good planning and good control, with sound industrial engineering principles undergirding them, should then make it possible for the definite advantage that goes with shorter lines of communication to pay off in the competitive situation.
2. Human relations can be immeasurably better as things currently stand in the industrial scene in the small plant. Again this is apparent to students of the centralization vs decentralization discussions that are now going on in industry generally. A small plant is a better potential place for good human relations, and students of human relations are quick to see this. The question, however, is "Does small plant management see these inherent advantages?" It appears that, by and large, they do not. And again this very definite advantage can be, and frequently is, dissipated by the indifferent techniques by which human relationships are handled in small plants.
3. Coordination, a major problem in large plants, can be greatly facilitated in small plants. But, again, small plant management must be equipped to take advantage of this competitive advantage.
4. The informal organization, the potentialities of which we are now just coming to recognize, has the possibility of more immediate and effective contribution to the small plant.

* * *

A final word, particularly to you younger men who are perhaps just starting out in the field of Industrial Engineering or who may yet be in college preparation for this, your life's work. By these remarks you may have received a gloomy picture of the possibilities of creative employment as an Industrial Engineer in small manufacturing plants. I know I have talked with some of you and heard your story that when you went to some small plants to discuss job possibilities the management stopped you dead in your tracks with the naive question "But just what is an industrial engineer?" I realize this has placed you in a very embarrassing and uneasy position. But it points up the problem that I have here been trying to underscore. That is, there is much that can and must be done, and as a matter of fact will be done, by industrial engineering techniques in small manufacturing plants; but it may yet be quite a while before the title Industrial Engineer appears on the payroll sheet of the very plants where some of this work can and most certainly should take place.

I do not propose here to be able to supply the answers as to how Industrial Engineering will ultimately prevail for what it is and what it can be in small western manufacturing plants. That it will succeed in its mission I have no doubt, but I know I tend toward optimism. This rose-colored look, however, is not from anything other than a deep-seated conviction that where in American business there is a real need, this need is somehow faced and met in due time. The timing, admittedly, is frequently slow-much too slow, in the opinion of those who believe they have the answers. Nevertheless, the trend toward better management in western plants is unmistakable and so I think it is only fair to assume that as the science and art of industrial engineering are made more clear through the various media of communications now and in the future available, the plain horse-sense of applying it will overcome the road blocks that presently appear in some cases to be almost insurmountable.

It probably will require of you young men a type of dedication very similar to St. Paul's who took the aggressive in presenting his Message to a world that resisted it, but which hasn't been quite the same since it listened. There has always been a place for industrial evangelism as well.

PRODUCTION ENGINEERING
IN SMALLER BUSINESS SESSION

Session Chairman: R. L. Johnson, Berkeley, January 30, 1953

AUTOMATION IN SMALLER INDUSTRY

Frank K. Shallenberger
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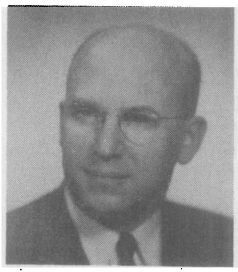


I find myself today in the position of ringmaster of a three-ring circus. I have accepted the assignment of talking on the subject "Automation in Smaller Industry." This means a discussion of both automation and of the small plant. I have also agreed to use the development of a new shell molding machine as a case history, and that is the third ring. Let us take a look first at the general subject of automation.

Automation is without question one of the most active subjects of discussion and conjecture in management today. I think it is the most exciting. The push button factory sounds like an engineer's wild dream, but such a plant could be built today. It could have a tremendous impact on our economy and on our society. It could mean an end to human wants. It could mean a 4-hour work day. It could mean a complete revolution in our economic and business life. There are no limitations to where your imagination can take you when you start thinking of the automatic factory, in which the only workers would be observer-technicians. But Buck Rogers' imagination must be curbed by practical limits if we are to be realistic, and I want to spend some time today in trying to appraise realistically the prospects for automatizing industrial processes, particularly in small plants.

Actually, there is very little new in automation. The word is of postwar vintage, and the subject has come to the fore in management circles only in recent years. But to find the origin of what we now know as automation, we must go back to the time of the industrial revolution.

It may surprise many of you to realize that a completely automatic plant was constructed as early as 1784 when Oliver Evans built a continous flour mill just outside Philadelphia (Fig. 1). This mill unloaded grain from boat or wagon and processed it to finished flour without human aid. This was not the only early installation. In 1833 the "victualling office" of the British Navy mechanized the manufacture of biscuits, and in 1869 (Fig. 2) endless monorails were induced into the meat packing industry in Cincinnati. These were the forerunner of the powered conveyors which Henry Ford set up in 1914. It should be noted that in many of these early applications the device did not necessarily eliminate the human operator. Often it merely gave him mechanical power to do what had been done manually before, substituted horsepower for manpower. In this sense it was mechanization and not strictly automation. Automation in the sense of control of industrial operations is more recent and may

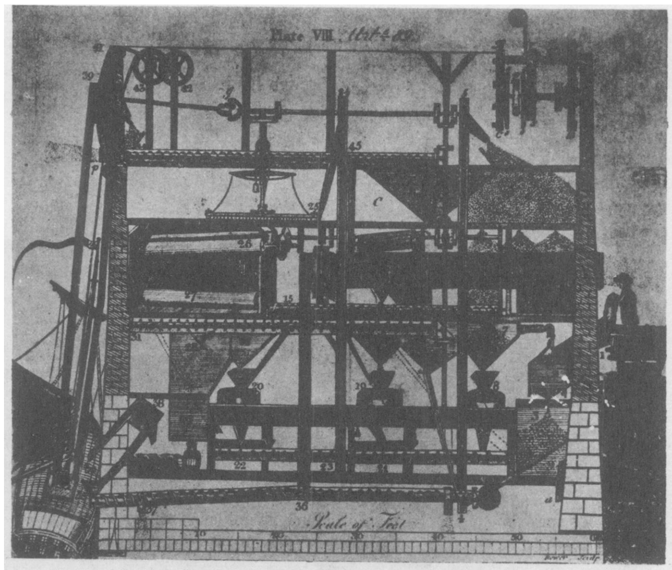


FIGURE 1. SCHEME OF THE MECHANIZED MILL, 1783
(Evans, Young Millwright and Miller's Guide, 1795)

FIGURE 2. ORIGIN OF THE MODERN ASSEMBLY LINE. CINCINNATI, c. 1870. (Harper's Weekly, 6 Sept 1873)

well be regarded by historians as the distinguishing characteristic of the second industrial revolution. In the first, the machine replaced man's muscles. In the second, automation will replace his brain as an industrial control device.

The process and chemical industries have been largely automatized for many years, so also have the manufacture of electric light bulbs, cigarettes, bottles, tin cans, and similar products. The A. O. Smith Company in 1920 built an automatic factory to make automobile chassis - a plant in which strip steel was automatically blanked, formed, assembled, riveted and painted and a complete chassis completed every 10 seconds, ultimately 10,000 per day. (Fig. 3). In 1948 two machines were built in England to

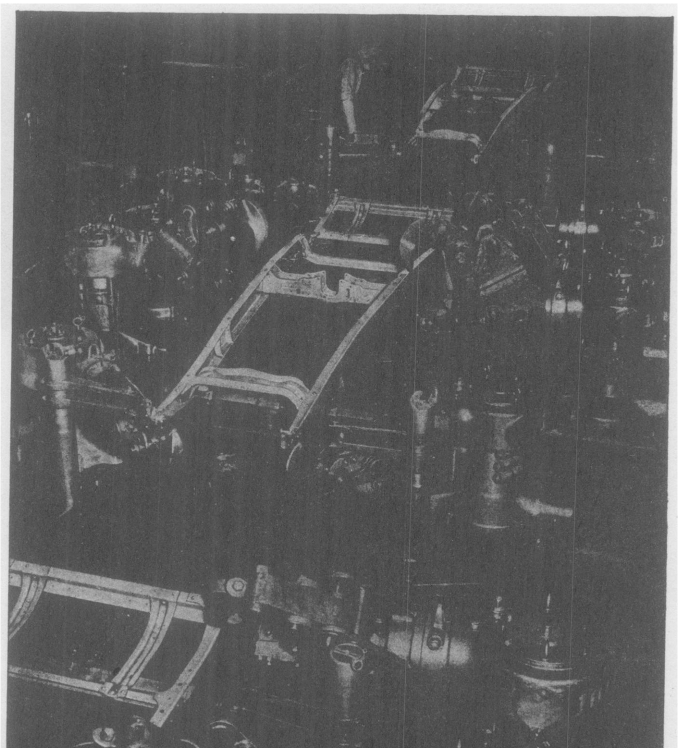


FIGURE 3. FULLY AUTOMATIC ASSEMBLY LINE: RIVET-SETTING IN A GENERAL ASSEMBLY UNIT. (Courtesy A. O. Smith Corp. Milwaukee)

produce radio sets automatically. The Ford Motor Company has had an Automation Department since 1947. To Ford, automation means automatic loading, unloading and handling of materials between machines. A typical installation is shown (Fig. 4).

Materials handling takes on added importance and

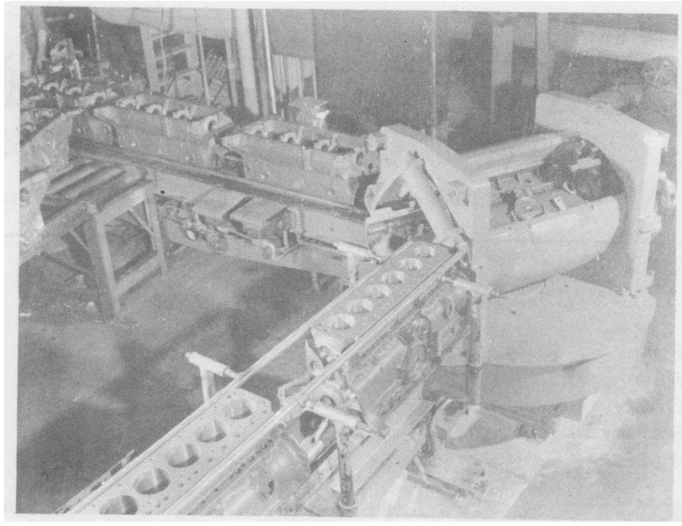


FIGURE 4. This unique two-directional "automation"device turns Ford 6-cylinder engine blocks end for end and revolves them upside down to facilitate motor assembly operations at Ford Motor Company's new Cleveland Engine Plant. Blocks are automatically loaded into compound turning device which positions block upside down by means of an 180-degree turnover and revolves the block so that the rear end leads for easy assembly of camshaft and crankshaft. A succeeding automation shuttle extracts the block from this device and automatically delivers it onto the assembly conveyor at left.
-FORD NEWS BUREAU

attention as the machine processes themselves become more automatic and as machining time is reduced by improved coolants and new cutting steels, or eliminated entirely by such processes as die casting, powdered metallurgy, etc. The transfer type machine in which the handling function is built in is of fairly recent origin. Actually, it is typically a large number of machines mounted on a common base, coupled together, and centrally controlled. Thus it combines both machinery and materials handling and automatically processes a part such as a cylinder head from raw forging to finished product.

The inspection function also has been automatized extensively, with automatic devices which count, inspect, sort, check performance; and so forth. Some of these, such as the crank shaft balancing machines in the new Ford and De Soto plants determine the amount and location of the out-of-balance condition, then automatically remove the right amount of metal from the right place to cement it.

In the last three years there has been a great surge of interest in automation. There have been research projects, magazine articles, and last month a new book was published on the subject. FACTORY magazine devoted a double issue to it. About a year ago the Russians jumped on the band wagon with an article in the USSR Information Bulletin describing in rather vague terms "The World's First Automatic Piston Factory". This looks like a fake, but it shows the kind of company you keep in this field. (Fig. 5)

Most of the new interest arises from the fabulous possibilities of electronic control. If such devices can pilot aircraft, direct gun fire, control the flight of guided missiles, why can't these same "little black boxes" also be used to guide the feed and cut on machine tools, control the movement of conveyors, inspect, assemble, and package the finished product?

It is truthfully said of such controls that they can see better, hear better, measure better than humans - they are more reliable, more powerful, more precise, think and move faster than human operators; they never get tired, don't make mistakes, don't talk back, are obedient and fully predictable. They have few personal problems, and they won't go on strike. The electronic controls can and are already being used for the direction of many industrial processes. The primary limitations to their use are tech-

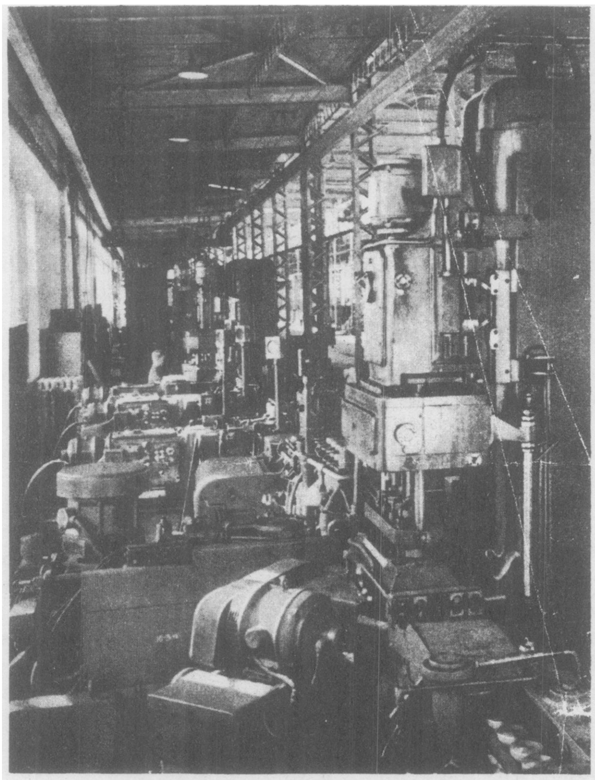


FIGURE 5

nical and economic. At present there are few standard components available for attachment to existing equipment; each installation requires individual and costly engineering, and most industrial engineers are simply not technically qualified to use these new electronic devices.

At the same time, there are many, many shops where electronic controls are neither necessary nor practicable. In most situations pneumatic cylinders, cams, solenoids, thermo-couples, limit switches, can do the job more reliably and at much lower cost. But the future potential of electronic controls is tremendous. The ability of these devices to think, choose, remember, to accept and use information fed in on a tape or punched card, to solve elaborate equations and to apply the solution to the control of complex industrial processes, make electronics the real key to the fully automatic factory of the future. This is the automation that goes beyond mechanization.

The application of electronic controls is by no means limited to industrial situations. You have all read of the fabulous electronic computors and their potential use in engineering mathematics, the sciences and statistics. Have you considered their application to sales, procurement, inventory control, quality control, and production control - or and to the prediction of future business events? Modern business machines have made possible great improvements in management techniques. Have you considered how future management will be influenced by the availability of continous up-to-the-second information on practically any phase of the company operation? No longer will management decisions have to be based on hunch or incomplete data - the computor will be able to produce the facts instantaneously. Wherever you can accumulate the pertinent basic data, the computor can tell you the exact probability of future occurrences, what the buyer or your competitor will do, what your volume will be next week or next year, what your chances or risks are in any management action. Computors will also automatize clerical operations, analyze performance, post accounts, compute and send out bills, handle payrolls, reorder, store vast amounts of information and produce it immediately when needed. The potential in agriculture, transportation, merchandising and other industries is at least as great as manufacturing.

It would not be right to leave this general subject of automation without some speculation as to its impact on management, on society, and our way of life. Automation is already here in many areas but it will not become widespread overnight. There will be many plants which will never enjoy extensive automation. At the same time most of the things we eat and use and wear will someday be made in factories where the only workers will be technicians and not producers. These will not always be products as we know them today, for automation often requires new material and complete product redesign.

Barring a serious depression, there seems little likelihood of widespread unemployment as a result of increase automation. Technology has always created more jobs than it has destroyed. Human wants are far from satisfied. The support of the aged, the demand of other nations whose aid we have undertaken, and the defense program appear to give more reason to feel a shortage than a surplus of workers. Automation will without question create a serious shortage of skilled technicians.

I do not wish to get involved in the sociological effects of automation, but I believe it important to point out that in automation we may find the key to the most serious human problems of mechanization, the monotonous, routine repetitive job. These jobs, the curse of modern mechanized industry are those which are most readily automatized. Automation seems destined to replace large numbers of unskilled and semi-skilled workers with a relatively few highly trained technicians whose function it will be to keep these fabulous and expensive machines operating. The challenge to educational institutions in developing and training these technicians is great, for we already have a shortage of such skills. We have much to learn in both aptitude testing and mass training to very high technical levels. It should be recognized that a new kind of engineer is necessary, combining skills in industrial, electronic, instrumentation and mechanical fields. In addition to technical competence, these engineers must be able to exercise a high degree of competent and intuitive judgement

The effect of automation upon maintenance, planning, personnel relations, sales, and other management functions will be almost as great as upon production. Out of this general discussion arises the question, where does the small plant fit in? Won't the need for large capital investment, for highly skilled technicians, for elaborate sales and production planning tend to concentrate industry in the hands of the large concerns and force the small company out of competition?

I believe we can shed some light on the subject by describing two machines and their automation for small plant use. The first of these is still in the developmental stage, has been constructed thus far only as a manually-operated prototype. But we are presently looking forward to its automation and perhaps we can think the problems of its automation out together today. The machine is a shell molding machine, specifically designed for small plant use.

Essentially the shell molding process consist of dumping a mixture of sand and thermosetting resin onto a heated metal pattern. The heat from the pattern penetrates into the mixture and cures the plastic close to the pattern. After the desired "build-up" has been obtained, the pattern is inverted and the uncured mix falls off, leaving a thin shell of half-cured mix clinging to the pattern. The pattern and shell are then put into an oven, where the shell is cured. After curing the shell is stripped from the pattern. Two shells placed together form the mold into which the metal is poured to form the casting. (Fig. 6)

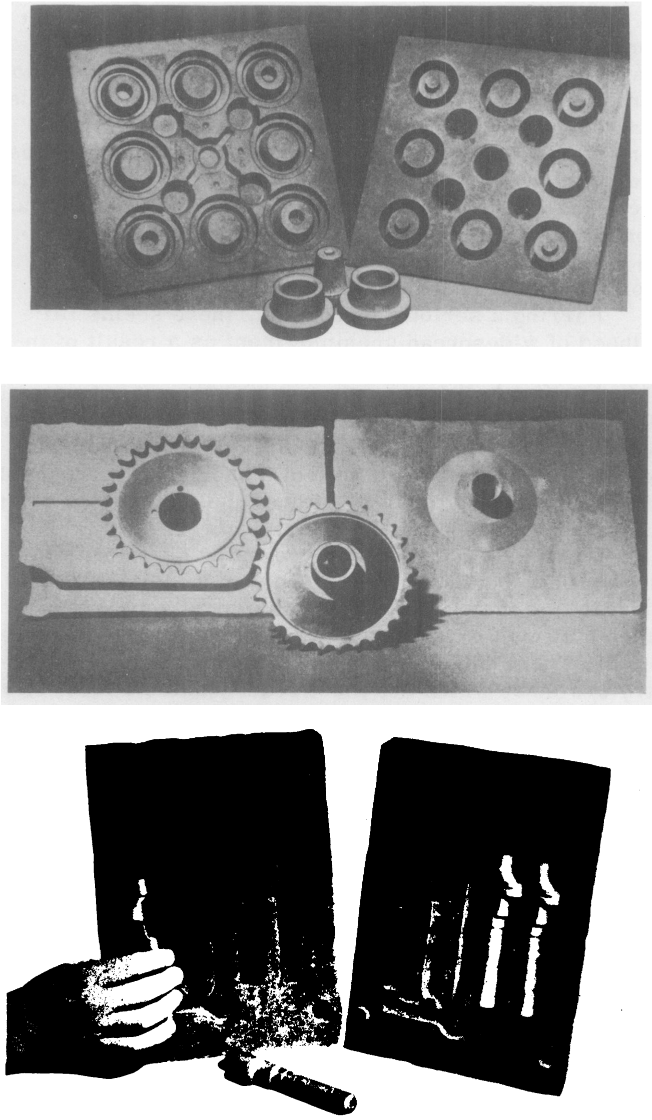


FIGURE 6

The primary benefits are extreme smoothness of surface and accuracy of dimension. There is little comparison between the ordinary green sand casting and the beautiful finish on the shell molding. Shell molded castings can usually be held to a tolerance of .003" per inch so subsequent machining consists for the most part of light finishing cuts and in many cases may be eliminated altogether. The shells are porous, so that gases can readily escape, and blowholes, except where a gaseous condition is present in the metal itself, are virtually unknown. The sprues and runners are much smaller than in conventional casting so there is less scrap to reheat. Flash or fins are virtually eliminated, and cleanup is greatly reduced. Because of the smooth walls and insulating effect of the shells, very thin sections can be readily cast. Materials handling is greatly reduced, since a few pounds of shell replaces perhaps a hundred pounds of green sand mold. Likewise floor space requirements are much reduced. Shells can be stored indefinitely without deterioration so more economical molding and pouring schedules can be worked out. And the process of making the shells can be readily automatized.

There are disadvantages, of course. The pattern costs are likely to be higher, for if you want precision in the finished piece, you must build precision into the pattern. The plastic costs 7 - 10 cents per pair of 12" by 18" shells. Of course this cost is quickly saved in machining. Techniques for holding the shells together during pouring are generally inefficient. Past practice has been to back up the shells with steel shot. More recently use has been made of cement or built-up cones to hold them together. Much remains to be done in this area.

I had the good fortune to see the process in operation in some of the larger Eastern Plants over a year ago. I described it to one of my classes and told them also that so far as I know, none of the foundries in the West were experimenting in the process. Out of this grew a class project to find why this process, so extremely successful in the East, was not creating more interest among foundries in the West. We found that there was inertia, lack of knowledge, and a feeling that the process was suited only to mass production. We were even asked, "With business so good, why experiment with something new?" We also heard almost universally the statement that there was no shell molding machines available at a price the small foundry could afford to pay. The foundry had two choices, either an inefficient manual operation or an automatic machine at a cost of $20,000 - $30,000 (Fig. 7). So we

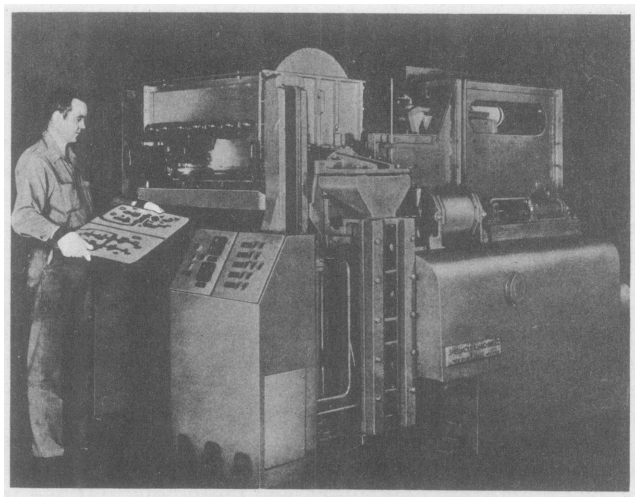


FIGURE 7 *Automatic shell production machine, Model SU-1, manufactured by Shellmold & Machine Co., Inc., New York, N. Y.*

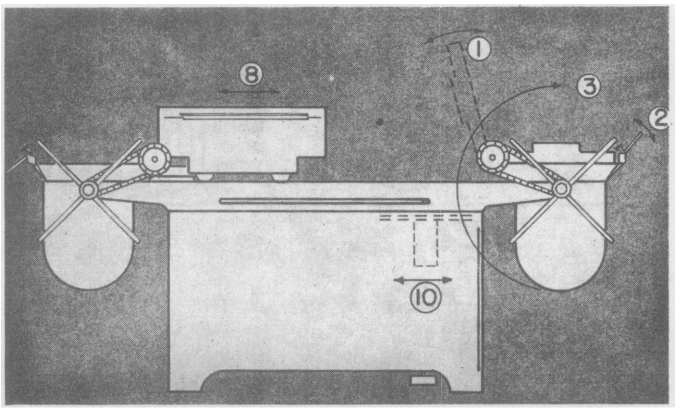
directed our attention toward building a machine efficient enough to compete effectively, flexible enough to handle short runs, and economical enough that the small plant could affort to make or buy it.

This was primarily an educational project, secondarily a service to Western industry. When the machine was complete, we opened our doors to everyone who wished to see it. Upwards of 200 visitors came to the Laboratory to see the machine and letter inquiries have been received from as far away as Norway and Bombay.

Recently a new company was formed to take on where the student project left off. An entirely new type of machine has been developed and is now in the service testing stage. It has the same original objectives, -- efficiency, flexibility, reliability and low cost. It can be made to sell for the price of less than one-half that of the cheapest Eastern machine and will have, we think, a productivity about 50 per cent greater.

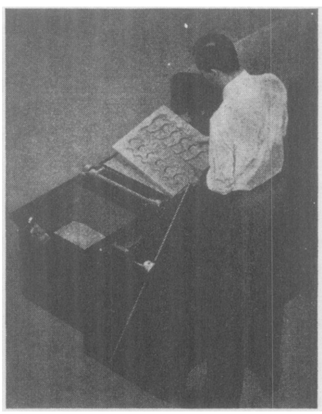
This machine obtains its high productivity from the use of two patterns and two dump boxes. Thus shells are produced alternately, the idle time during the curing of one being used to coat the other pattern. One oven and one stripper serve both patterns. Patterns are hinged to the dump boxes to insure positive alignment.

The machine is basically hand operated, but already the company is being pressed for a more automatic machine, and I would like to tell you our thinking to date on the matter. (Fig. 8 & 9).



Example of automation opportunities applied to equipment for use in small foundries. Diagrammatic view of the Shalco shell molding machine, showing steps where automation can be put into use. Figures refer to the accompanying text. (1) Closing the box. (2) Clamping. (3) Inversion. (8) Moving the oven. (10) Moving stripper.

FIGURE 8



Photographic side view of same machine with box and capstan in foreground; oven is seen at the right. This is a hand-operated prototype, to be further mechanized.

FIGURE 9

The basic movements in the machine are: 1. Close box, 2. Clamp, 3. Invert, 4. Invest, 5. Revert, 6. Unclamp, 7. Open box, 8. Move oven, 9. Cure, 10. Move to second pattern, 11. Move stripper, 12. Strip; Repeat for Box 2.

At every stage in the development of the machine, it has been borne in mind that at a later date, we might wish to automatize it, so before we froze the design of any movement, any mechanism, -- we gave at least preliminary thought to how it would be automatized. However, attention was concentrated on the hand-operated machine because it was simpler, was what the foundries seemed to desire, the process time cycles were not thoroughly settled, and it keyed in better with our overriding objective of keeping the cost down.

For the future, our thinking runs somewhat like this:

The machine could be made 100 per cent automatic. Many of those in the East approach this. But there is little object in automatizing unless there is something to be gained in labor-saving, quality, productivity, safety or similar benefit.

Only complete automation would eliminate the labor. There is little point in having the worker stand around and watch the machine work. But partial automation might enable him to run two machines or assemble shells, cement clamp, or perform similar work. Automation would help reduce the skill requirements, but actually there is very little required, even on the manually operated machine. The effort involved is minor. Automation should reduce the variability in the process and product, by standardizing the investment and cure time. But this is a new process, and more ivestigation will be necessary to determine the importance of these times. Automation might increase productivity somewhat by forcing adherence to ideal cycle times, and would "pace" the operator.

Which of these steps should we automatize?

1. Close box

This is a simple hinge action. Originally this movement required considerable effort, expecially with a heavy pattern plate. We have reduced the effort to practically nothing by using a 2:1 ratio in the sprockets and by adjustable counter-balancing springs. In an automatic model, we would probably use an air cylinder to open and close the box Air is already at the machine for stripping and spraying. This might permit elimination of the clamps, for air cylinder would hold the pattern closed to the box.

2. Clamping

If clamps are necessary, they will be air clamps, actuated by a valve which opens when the dump box starts its inversion. These may be added even on the hand model so that the operator turns the capstan continuously. Alternatively a Geneva movement could close the clamps mechanically.

3. Inversion

The boxes are presently inverted by means of the capstan. We are inclined to favor rotation by means of an air cylinder on an automatic model. In hand operation the operator gets a "feel" for the right speed of rotation, and we have determined this speed by taking motion pictures of the hand operations. This data will be used to calculate air piston requirements for the automatic design.

4. Investment

The dwell during the build-up of plastic and sand influences the thickness of shell. The ideal here is a balance between shell strength and materials cost. Once the correct time is determined, the control is not difficult. An inversion timer, like an hour glass, would be appropriate in the case of a hand operated machine and an electric timer in the case of the automatic machine.

5. Reversion

This would be accomplished in the same manner as the inversion.

6. Unclamping - same as clamping.

7. Opening - same as closing.

Automation of the steps involved in closing and inversion of the dump box, just described, would afford the operator adequate time to attend another machine or to clamp or cement shells.

8. Move oven.

This is a reciprocating motion, simple to automatize. But there is little benefit from a quality standpoint, for the timing is not critical and could be about as well controlled by an indicating bell or light. There is no safety involved and very little effort. Finally, this operation immediately proceeds the stripping operation, which we have determined should be manually handled in any case. Therefore, the operator will be at the machine when the oven move takes place. An air piston or gear motor and sprockets and interlocks would add over 10 percent to the sales price of the machine, an increase we at least tentatively consider unwarranted.

9. Stripping

As in most machines, the most difficult phase to automatize is the loading and unloading. Here the loading is merely replenishing the mix in the dump box, which is simple and occurs only every dozen cycles or so. A hopper above each box would be appropriate in a production operation. The unloading is the stripping and removal of the shell. Automation here would involve fingers to lift and remove the shell, carry it aside and dispose of it. This is the most critical operation, the place where things are most likely to go wrong, where inspection is necessary to assure quality and to detect errors in previous steps. For these reasons we have no intention of automatizing it.

10. Move stripper

This operation is much like moving the oven. It takes place immediately following the operator's return to the machine after disposing of the shell. We have contemplated coupling the oven and stripper together so that they would move in opposite directions.

From this analysis we conclude that our first machines should be manual, perhaps with automatic clamping. They should be equipped with simple timers which notify the operator but do not actuate other phases of the cycle. Later, we will add automatic closing and rotation of the box. It appears unlikely that we will go much beyond this, for the savings do not appear to warrant the additional cost. We are very conscious of our costs for the machine has been designed primarily for small plant use, and we have been able to price it at less than half our nearest competitor. Such automation as we have proposed above raises the cost about 50 per cent.

I would like to add here a brief discussion of another machine, which, while not designed specifically for small plants, is ideally adapted to such use and to automation. I am sure that many of you are familiar with the Magna Drill, recently developed by the Magna Engineering Company and made right here in Berkeley.

This to my knowledge represents the first really new thinking on drilling in recent years. It is predicated upon the assumption that since there is little that can be done to speed up the drilling cycle itself, the greates opportunities lie in shortening the load and unload elements and in drilling more than one hole at a time. (Fig. 10)

The outcome of this thinking is a highly flexible, highly productive drilling machine with very important implications for the small shop. Basically, it is a machine mounting as many drill heads as desired, in such a way that they can be quickly arranged for simultaneous multiple drilling in any plane. Thus it can perform operations similar to the elaborate Excello, Kingsbury or other multiple drilling machines without the high initial cost and with complete flexibility for changeover. It brings to the job shop much of the efficiency of the long run, continuous production tooling of specialized plants. I can best illustrate

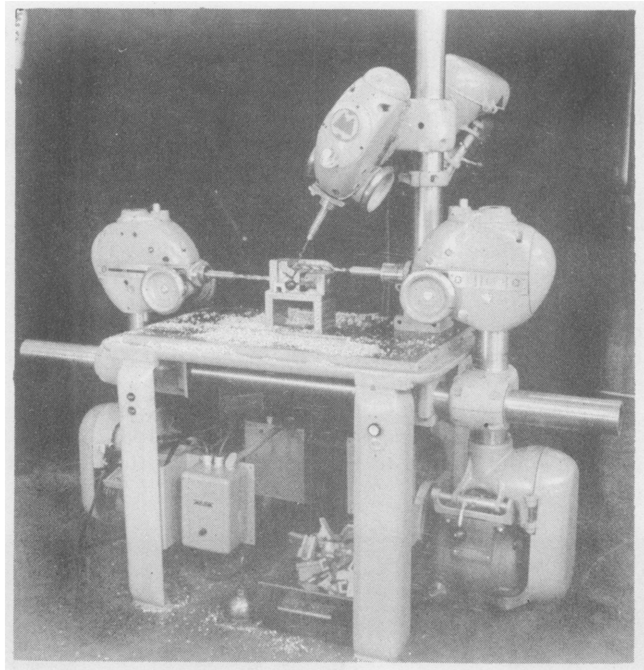


FIGURE 10

these characteristics by describing several jobs as set up on this machine.

In the first of these, as originally set up, the job took 2 1/2 minutes per piece; now it takes 1/2 minute. There were 5 set-ups, including 4 jigs; now there is one set up and $185 worth of tooling plus a $265 index table. In the first station, the set screw hole is drilled, in the second the axial hole is drilled and in the third hole the set screw hole is tapped. Loading and unloading is so rapid that the operator has time to assemble this part to three mating parts -- in other words, production time has been cut to one-fifth and the assembly operation is thrown in "for free".

In the second case, part is drilled and tapped. Previously, production was 40 units per hour using tumble jigs for the two holes and another jig for the tap. Now production is 120 units per hour and the tooling cost only $125. Moreover, the operation is much easier for the operator has only to pick up the part, not the jig.

In the third case, four holes are drilled and two tapped at the rate of 1100 per day.

All these operations and two or three others are performed on the same machine in runs of 4 - 5,000 units. Change-overs take only 2 - 4 hours.

To illustrate the extent to which such a machine can be automatized, I would like to mention that a 5-head unit has been set up in a little shop in this area to do a series of second operations on an ordnance part. This is completely automatic with the exception of loading and deburring. The production rate is 1200 per hour.

What can we learn from these examples? What significance do they hold for the small plant?

I believe their most important significance is that some one is doing something for the small plant, that there are equipment manufacturers who are thinking and designing and planning for the small plants' specific problems. In this connection allow me to quote two other examples.

General Electric has developed an automatic lathe equipped with what they call "playback control". As the machinist makes the first piece, his operations are recorded on a magnetic tape. Then in the same manner as a tape recorder plays back your voice, this device plays back the operation, automatically repeats the operation on that lathe, or any number of other lathes so equipped. It also repeats all the hesitations and trial cuts made by the machinist, but presumably these can be edited out, by cutting and splicing.

This machine sounds pretty wonderful, but listen to this one! The Arma Corporation has developed an automatic lathe directed by a punched paper tape similar to a player piano roll. This lathe reportedly turned out in 4 minutes a piece that it took a skilled machinist 30 minutes, referring to blueprints, to produce. In other words, it was set up and turned out the first piece in about two-thirds the time required by the conventional lathe to turn out one piece and thereafter turned them out about 8 times as fast as the conventional lathe! And the small plant would not have to mortgage the shop to get such a control unit. It was coupled to a standard engine lathe at an estimated cost of only $1500. And what is even more startling is the accuracy of such control. Utilizing the principal of "Feed-back" the machine monitors itself and on this operation held a tolerance of .0003.

Neither of these lathes is yet available, but I am sure their significance for the small shop is readily apparent. (Fig. 11 - Fig. 12)

All these examples, I believe, demonstrate that some considerable degree of automation is practicable in small plants, that the payoff is there if you go about it logically and realistically, that automation does not necessarily require a large capital investment and long-run continuous production and does not necessarily inhibit flexibility.

The experience in automatizing the shell molding machine and the thousands of industry-wide applications of pneumatic cylinders, solenoids, limit switches and so forth indicate that standard, off-the-shelf components are available and adaptable to automatizing production operations. There will be more available as the demand grows. Electronics are not necessary in most situations, In fact, electronics are only a part of the automation picture, useful primarily where programming, complex control or full automation is involved.

These examples indicate, I believe, that there is nothing sacred or necessarily desirable in 100 per cent automation. It's like any good methods work. You "let the punishment fit the crime", buy whatever fits your pocketbook and needs, go only as far as the payoff warrants. If the stakes are high and you can afford it, you pull out all the stops and make the job fully automatic. But, maybe circumstances only warrant making it 50 per cent or 10 per cent automatic. If so, that's as far as you should go. You don't buy automation for automation's sake. It is probably wise to steer clear of the really difficult areas like loading and unloading and assembly. Pick the ones where you get the biggest payoff with the least expenditures. Standardize on your automation devices for easier know-how, maintenance, interchangeability. It is generally poor economy to build your own devices. Where possible get complete, packaged units -- drill press feeds, automatic index tables, pneumatic vises, packaged hydraulic units.

The determination of when to automatize is strictly a matter of dollars and cents. The cost of the automatized operation should be compared with the non-automatized operation. Ford reportedly feels automation is justified if a $3000 expenditure will replace a man. Other companies feel a much higher expenditure is justified. In any case, automation should not be sold short. You can be liberal in estimating the payoff, for the intangibles and unpredictables in the form of morale, quality, consistency, safety, lower-

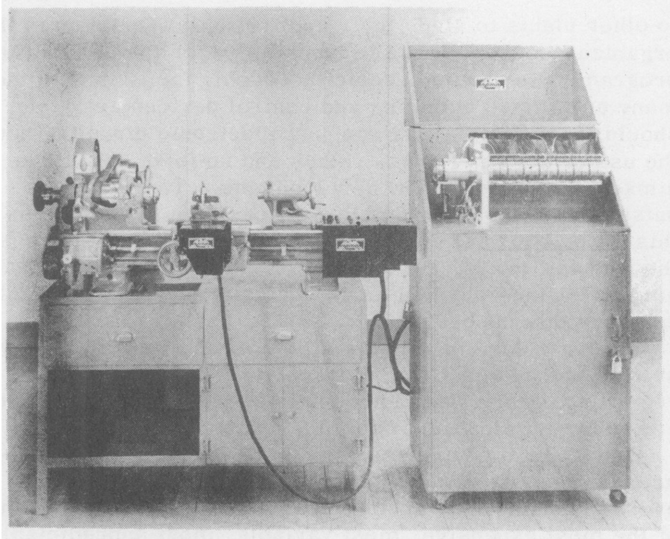


FIGURE 11

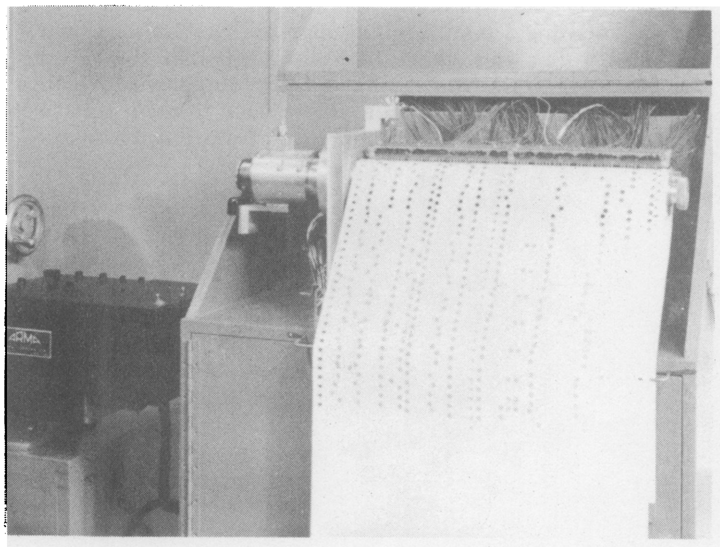


FIGURE 12

ed skill requirements, and so forth, usually mean a much faster return than expected.

Automation takes time and takes talent and it takes money. What about the small plant which hasn't the time or technical ability or simply can't afford the capital investment required? Many small plants, no matter how fast the potential return on the proposed automation, always seem ab able to point to many other opportunities where the same money could be invested and pay a much larger return. This seems to be a chronic ailment among small concerns and most of them are quite conscious of the improvements they could make if they could afford it. To them it is academic to say that the payoff should be one year or two years, when they don't even have the funds to take advantage of the opportunities which would pay off in six months, or three months. I know of no solution. Perhaps it is borrowing; perhaps it is new capital; perhaps it is a schedule or project priorities and a better budgeting of the necessary funds and time.

But there are cures for lack of knowledge about these matters -- conferences such as this; reading; visits to other plants to study their applications. One man in the organization should have responsibility for the automation program. He should become thoroughly familiar with the many and varied actuating and control devices available, should learn simple circuits, not electronic circuits, but the use of limit switches, relays and so forth, should keep himself informed on new developments. There are few outsiders to whom the small plant can turn for advice in this field, but I believe a new profession will develop over the next few years, the automation engineer. If I were a student engineer looking for a specialty, I would seriously consider this opportunity.

But knowledge is only the start. It also takes an active, uninhibited imagination. It takes "thinking" automation, regarding each job and each part of each job as a prospect either for elimination or for improvement.

One of the big hurdles is the union problem. The primary savings from automation are labor savings, and every plant manager should clearly recognize labor as one of the most expensive, most variable, most unpredictable factors with which he has to work. Current wage levels, low productivity and related labor difficulties are among the most important incentives to automation. At the same time organized labor opposition has been one of the primary deterrents. In many plants the union is able to block assigning a man to more than one machine, so partial automation would have little to offer other than giving the man more idle time. I have seen companies forced to mount several machines on a single base to meet this problem. I have seen them give special classification to a worker to avoid union restrictions so they could utilize the time made available by automation. Fortunately all unions do not offer such opposition.

This business of automation is big. I hope I have been able to add a little to your background and perspective on it. The push button factory is coming; in fact it is already here in some fields. But it won't sweep industry overnight. And some areas it may never affect greatly. Automation won't push the small plant operator out of the picture. In many ways it may strengthen his position if he is awake to its opportunities, if he recognizes it for what it is, understands it, adapts himself to it.

Automation is perhaps not the biggest thing in our lives but it is certainly one of the most important phenomena of our generation. It has tremendous potential benefit for mankind. It's not really new; it's only the logical end to imaginative, uninhibited methods improvement.

Let me suggest that you read all you can get about automation, that you think about it, talk about it. Don't close your mind to it just because at first glance you can't quite see how it fits into your plant. Take a fresh look at your own operations, see where you might utilize these new techniques, new equipment. Large or small, you will find some opportunities for your plant. Let me suggest finally that when you do consider it, you carry your thinking far beyond just automatizing your present operations and present equipment. Your real opportunity may lie in entirely new materials, new processes, new product designs which lend themselves to automation.

This is the kind of approach which will pay off.

A CASE STUDY IN THE RELATIONSHIP BETWEEN DESIGN ENGINEERING AND PRODUCTION ENGINEERING

Joseph P. Hahir
Manager of Production
Schlage Lock Company
San Francisco, California

In looking back over the more than thirty years that I have been connected with the manufacturing business, I remember many cases of trouble and grief encountered because a product was tooled up and put into production direct from the design drawings without any consideration of Production Engineering.

There is a concentrated effort being made in this area to call to the attention of those manufacturers, who have been slow to apply Production Engineering in their plants, the advantages to be gained by the proper application of Production Engineering. Some of these manufacturers, particularly the smaller ones, may feel that they cannot afford to have separate Design and Production Engineering Departments with separate groups of engineers in each. I hope to be able to show later in my talk that it is not always necessary to have separate departments. The main point is that the function of Production Engineering is carried out.

I think that you will agree that the problems connected with the manufacturing of an item which has no mechanical operating functions such as a set of fireplace andirons, are entirely different from those encountered in manufacturing an item which has to perform a mechanical operating function during its entire lifetime in the hands of the customer. Examples of such items would be calculating machines, door locks, outboard motors, typewriters or any one of thousands of other items which could be brought to mind.

While the problems connected with the manufacturing of andirons and those connected with any one or the other of the mechanical items mentioned may seem to be different they are so only to a degree. The main difference between the two cases cited is that of the number and the complexity of the problems. It is just as easy to go broke in the andiron business as it is in the automobile manufacturing business if the total cost of manufacturing exceeds the Selling Price of the article.

One of the main factors that keeps the manufacturing cost at the lowest possible figure is properly applied Production Engineering. If the andirons are not studied for various things which make for low cost of manufacture, you may rest assured that the manfucturing costs will be high. The same is true only to a greater degree for the other items from can openers to automobiles.

I am sure that most of us will agree that the main reason for being in business is to make money and a profit. In some remote cases, however, we find people in business to lose money.

For example, we hear of cases where professional men, such as doctors, lawyers, actors or others, who, on account of present tax laws, often engage in the manufacturing business to purposely lose money. Apparently the only thing they gain by this is the satisfaction of spending their surplus money instead of sitting back and watching the government do it for them. For the purpose of our discussion, we will not consider this type of business man but will think only of the people who are in business to make money.

Now, if any person, or firm, in the manufacturing business is to stay in business and operate at a profit they must watch their manufacturing costs. If the product being manfactured is intricate in design and is relatively complicated mechanically, great care must be exercised in the tooling and methods of manufacture used in its production. In our discussion here today, we will not go into the field of Design Engineering or into the qualifications of what it takes to make a good Design Engineer. This is another subject which could be discussed at length.

Production Engineering, or as it is sometimes called Manufacturing Engineering, enters the picture between the time that an item is completely designed and the time it is put into production. One of the primary functions of Production Engineering is the study of all phases of the manufacturing processes to insure the manufacture of the product at the lowest possible cost.

Or, to express it in other words which I quote from an article written by Mr. Gilbert P. Muir in the October 1952 issue of "The Tool Engineer" titled "Westinghouse: Engineering on Call". "By Westinghouse definition, manufacturing engineering is the art, or science, of guiding the conversion of raw material into the manufactured product by the most economical process, or method, possible under prevailing conditions and requirements."

It is generally agreed that manufacturing cost is made up of material cost, direct labor cost and overhead cost, or as it is sometimes known, burden. In some methods of calculating costs, the overhead costs are further broken down into such component items as indirect manufacturing expense, costs of sales and general and administrative costs. Usually, such items as costs of sales and general and administrative costs are set by conditions beyond the control of the manufacturing personnel and for this reason will not be considered here.

In his work of studying the product as designed, the Production Engineer works with the main component costs of production, namely, the material cost, the direct labor cost and some items of the indirect manufacturing cost or the overhead.

Each of these costs is carefully scrutinized by the Production Engineer in arriving at the lowest possible manufacturing cost.

Perhaps, at this point, the question might be asked, "Why is it necessary to have a separate Design Engineering and Production Engineering set up? Certainly every design engineer knows all about the manufacturing operations and such things as direct labor material costs, overhead and the like. If this were not true, how could he possibly become a Design Engineer?"

This is a very good question and without casting any aspersions on the Design Engineers of which I number many among my personal friends, I often wonder how some of them ever did become Design Engineers. However, the correct answer is that the field of mechanical engineering is so vast that under present day conditions of specialization, no one man can be proficient in all fields and that as a man specializes more in one field, it is at the expense of keeping up with current developments in the others.

In order to try to show the relationship between Design Engineering and Production Engineering, I am going to take a typical case of a new product from the time it is designed until it is shipped out the door to the customer and is giving satisfactory service in the customer's hands. This new product which is to be designed and manufactured is to be within, and added to, a previously established line.

This statement is made because the procedures to be followed may be entirely different if the manufacturer is introducing a product entirely foreign to his regular line and with which his organization may not be familiar.

Management and the sales organization will usually work out the specifications for the new product and turn this specification over to the design engineer for design of the item. The case study being considered is that of a new model door lock which was recently introduced by the Schlage Lock Company into their regular line of hardware. This new line replaced a line which had been previously manufactured, but which became out of date after many years on the market.

The new line of locks was started through the design department by means of a letter from management at the request of the Sales Department. The following requirements were laid down by the Sales Department.

1) The lock must be capable of adjustment so that it can be installed on a door with equal projection on both sides of the door.
2) The lock must be capable of permitting the outer knob and cylinder unit to be removed without removing the lock from the door.
3) The manufacturing cost should not be increased.

However, before we go further into how the Sales Department's request finally turned into a completed item ready for market, I would like to digress and say a few words about Design Engineers. My remarks will apply to the average Design Engineer. We find that many Design Engineers either do not know, or, in some cases, do not care anything about the problems encountered in the manufacture of a product. Neither do they seem to know, or care, anything about the use and operation of a product in the field.

I am sure that many of you have had occasion to use an item which you have purchased, such as, perhaps a can opener, a lawnmower, or any one of a hundred other items and your first reaction is "the guy who designed this sure never used one of them". Likewise, many a production man has had a product handed to him to manufacture and his first reaction is "the guy who designed this sure never had to make one of them".

Perhaps, by this time, there are some Design Engineers, or others in the audience who are taking exception to my remarks. So, in self defense, I am going to read to you a short poem, written by a Mr. Ken Lane, a Design Engineer for the General Electric Company.

"AS SOME MEN SEE US"

The Designer bent across his board
Wonderful things in his head were stored
And he said as he rubbed his throbbing bean,
"How can I make this thing tough to machine?
If this part here were only straight
I'm sure the thing would work first rate,
But t'would be so easy to turn and bore
It never would make the machinists sore.
I better put in a right angle there
Then watch those babies tear their hair.
Now I'll put the holes that hold the cap
Way down in here where they're hard to tap.
Now this piece won't work, I'll bet a buck,
For it can't be held in a shoe or chuck.
It can't be drilled or it can't be ground
In fact the design is exceedingly sound."
He looked again and cried -- "At Last --
Success is mine, it can't even be cast".

While the above may be somewhat extreme, nevertheless there is an old saying that where there is smoke, there is fire and we can conclude that there is at least one Design Engineer who must have a guilty conscience or he would never have had the inspiration to write the poem. In defense of our Design Engineers, I am sure that none of us feel that they go out of their way to make things difficult to manufacture although I think that it would not be difficult to build up some favorable arguments from production men on this matter. We do know from experience, however, that many products are not designed for economical manufacturing.

Now to go back to our case study we find that as time goes by the Design Engineer with the aid of the model maker will consider and reconsider many ideas and will eventually come up with a product satisfactory to the management and the Sales Department. It is at this point that the Production Engineer should step in and take over. It is at this point where many companies, both large and small, make a very serious mistake.

Perhaps the Design Department has taken a long time to design the product and, more than likely, the sales department has taken orders for the product and created a demand for the item. Naturally, by the time the design is ready, management is so anxious to get the item into production, that they are tempted to short cut the production engineering. Then, over the protests of those who know what is going to happen, the tooling will be ordered and the item put into production directly from the design drawings.

Only those of us that have been through what follows such a decision know what the inevitable results are. In most cases even management cannot help but know what is going to happen, but for reasons which often puzzle those of us who know what is going to happen, they go ahead and by-pass the Production Engineer. I cannot help but compare the procedure to a man who goes on periodic benders over week ends.

He has done it before and he knows just exactly how he is going to feel when he does it again. He usually goes ahead and when Monday morning comes around, he wakes up with terrible after effects and usually vows that he will never do it again.

In the case of management placing an item in production without proper production Engineering, they cannot help but know from previous experience just what they are in for, but, like our friend on the bender, they go ahead with the procedure and wake up with bad after effects and, perhaps, with the resolve that the next new product they introduce, they will do the job right. However, again like the man on the bender, they always seem to come up for more. I am sure that, if most manufacturers who indulge in the practice of overlooking Production Engineering, really knew what it was costing them in production delays, excessive tool costs and other factors, they would not even think of by-passing the Production Engineer.

Since one of the reasons why manfacturers are tempted to by-pass Production Engineering is supposedly to save time in getting a new item into production, we should stop and consider the fallacy of such thinking. I am certain that most of us who have been through the introduction of new products by the previously mentioned short cut method, or by the proper method of Production Engineering the product, that the statement can be made that the product will actually be in production faster by the proper method than it will by the so-called short cut methods. This is true because by the time the product is tooled and retooled and worked over many times by the trial and error method more time is actually consumed than it would have taken to do the job right in the first place.

Another very bad feature of trying to place an item into production without proper Production Engineering is that very often there are so many changes that have to be made in the tooling and manufacturing methods that compromises are made which affect the production of the item as long as it is being produced. This comes about from trying to save the investment in tools and processes when it is inevitably realized that the job is off to a bad start.

We will now assume that a manufacturer recognizes the value of Production Engineering and will see what he can expect by having his product analysed by a Production Engineer between the time that it is designed and is placed in production. The function of the Production Engineer is to take the product as designed and go over it with a fine tooth comb and make what changes are necessary or supplement what information is not complete after the designers have completed their work.The Production Engineer will make what changes are necessary to permit the item to be manufactured at the lowest possible cost and make it a servicable item.

If the Design Engineer is also a Production Engineer and is capable of designing and engineering the product for production, then, of course, there is no need of a separate group. It is, of course, possible that one individual can be proficient in both fields just as much as it is possible for a tradesman to have two trades and be proficient in both. I will touch on this matter later on.

When the product as designed has been turned over to the Production Engineer, there are many things that will be studied and considered in arriving at the lowest possible manufacturing cost and the production of the most servicable item.

First we have the proper selection of materials to be used. The materials will be considered for many factors such as saving weight, increasing strength, corrosion resistance, ease of finishing, and whether material is standard. This study will include the consideration of standard mill tolerances, widths, edges, tempers and other factors which, if varied from, can cause trouble or increase costs or make procurement difficult.

For example, the designer will often set material tolerances which are not in conformity with the commercial limits as set by mill standards. When this is done, it more than likely involves paying extra for the material and delaying delivery because of special mill runs. Often, the designer will specify a size of material which is not carried in warehouse stock, or which is not a regular mill standard, when the manufacturer may have in his own stock a size which is close enough to make the item. The Production Engineer will study the entire problem and determine whether or not to use the regular material or to stock a new item. Perhaps using the substitute item might involve more scrap loss than if a new item were put into stock, but taking into consideration the small quantity extra involved in buying the new item and comparing it with the cost of the regular item which might be bought in large quantity, the Production Engineer would find it less expensive and more convenient to use the regular item despite the fact that there would be more scrap loss than a new item might have.

Next, we have the matter of manufacturing tolerances which are often not considered by the Design Engineer, or if considered, are improperly applied because of ignorance or carelessness in the proper application of manufacturing tolerances. How many times have we seen drawings with dimensions having tolerances of ±.001 or ±.002 on dimensions which fit the air and which, in many cases, could have tolerances of ±.010 or more, even in some cases of having fractional dimensions with tolerances of ± 1/32. I think that the reason for this is that the designer does not know enough about the manfacturing operations to know what tolerances can be held by the operations as normally performed on various production tools and what it usually costs to hold close tolerances in the manufacturing operations.

One of the problems which gives the production department a great deal of trouble in this connection, is the use of so-called standard or block tolerances. This use of block tolerances may be known to some of you by other names, but in our consideration of the problem, it refers to the use of previously established limits which appear in the title block of the drawing or tracing, from which the prints are made. In a great many plants manufacturing the types of products we are considering, these block tolerances are on the following order:

± .005 inches on all decimal dimensions
± 1/64 inches on all fractional dimensions
± 1/2 degree on angular dimensions

In addition there may be limits set on such things as concentricity, fillets, radii and others.

Many times the designer will be working on a particular drawing and will feel that the standard block tolerances may be too broad for the function he has in mind and feels that closer tolerances may be necessary. Instead of taking the time to analyse the problem carefully he will very often (supposedly to save his own time) change the limits in the block tolerances, say from the regular ±.005 to ±.002, thereby forcing the tool designer and manufacturing department to live up to extremely close tolerances on all dimensions where as it may be necessary to hold only a few dimensions to close limits.

The Production Engineer will note these things and make an analysis of the drawing and consider the available manufacturing methods and equipment and suggest the opening up of close tolerances to wider limits where close limits are not necessary. At this point, some Design Engineers who have had experience with some Production Engineers will come forth and say that the Production Engineers are always wanting more liberal tolerances and, perhaps, can point to examples where the broader limits requested will affect the mechanical functioning of the product. It must be admitted that this has happened and will happen because of the difference in thinking normally existing between the Design Engineers and the Production Engineers. However, it is the function of the Production Engineer to study the matter sufficiently so that the only dimensions to be questioned would be those which are not functional and which do not have to be held close.

Another very important factor in the matter of close tolerances is that concerning the type of production equipment which is available in the manufacturers plant for the production of the item. It is possible to manufacture any item to the closest of tolerances if expense is no factor. There are machines available which will produce parts by grinding, honing or lapping and will produce these parts to very close limits. However, if the manufacturer has no grinding, honing or lapping equipment but has only turret lathes, or automatic screw machine, it is obvious that no drawings calling for tolerance in tens of thousandths should be permitted to go into the Manufacturing Department with the expectation that parts to the limits mentioned can be produced directly on such machines.

Next, we have the matter of removal of burrs and sharp corners. As many of you know, it very often costs several times as much to remove burrs and sharp corners from a part than it costs in labor and material to make it. Yet, many of our design engineers will just arbitrarily add a note to the drawing to "Remove all burrs and sharp corners" when it either is not necessary or, if necessary at all may be only on one or two places at the most.

Perhaps nowhere in our many manufacturing plants in this country is there more efficiency in all phases of manufacturing than in the automotive industry. This being the case, suppose we take a look at the way the matter of handling the problem s of burrs and sharp corners is handled in the automotive industry. In the passenger compartment of an automobile which is the place where the customer spends most of his time while using the automobile, one rarely finds any place where the customer can get cut or damage his clothing. This is because every effort is made by the manufacturer to see that there are no burrs or sharp corners on any of the parts. The same holds true for certain of the mechanical working parts, such as, the gears in the transmission and differential. All such parts are carefully deburred so that no loose particles of metal from burrs will become dislodged and cause trouble.

Yet how many of us who tinker with our own cars as a hobby or who take pleasure in adding accessories to the car ever come out of a session without cut fingers or torn clothes? I, personally, have emerged from under my car with my hands looking like I had been handling bulk razor blades. The Production Engineer will consider the function of all parts and will see that the notes covering the removal of burrs and sharp corners will apply only where needed.

Another factor to be considered here, is the means of removing burrs and sharp corners after it has been decided that it is necessary to remove them. Many plants do not take any definite cognizance of the problem but leave it up to the discretion of the foreman or the workman to find ways and means to rem ove the burrs and sharp corners. Recognizing the fact that the removal of burrs is often a costly operation the Production Engineer will provide the proper methods and tooling for their removal. The removal of burrs and sharp corners is just as much an operation as any required in manufacturing the part and should appear on the operation or route sheet, the same as any other operation.

We next have the matter of finishing the parts if the article being produced is one which requires a finish. Many products, such as door locks, require finishing operations, such as polishing, plating, painting, or other surface treatments. In many products, the cost of finishing is greater than the cost of labor and material for making the product. For this reason, great care must be taken in the selection of materials and the method of fabrication so as to insure the lowest possible finishing cost. If the part being m ade is one that can be made from a brass casting, or a brass forging, it might require considerable study to decide which one would be the better to use. In most cases, a brass sand casting would be much lower in cost than a forging, but after taking into consideration the machining costs of each and the loss due to defective, or porous castings, it might well be that the forging at a higher cost would be better than the casting. Very often the shape of a part will add many cents to the cost of finishing, whereas, a slight change in the design of the part would lower the cost to a great extent.

Another factor here is that of the trapping of cleaning and plating solutions in the parts. If parts have blind holes or recesses where such solutions can be trapped, it makes for very slow handling in the plating operations which, of course, in turn, increase the cost of finishing the article. The Production Engineer will study all such parts and suggest changes in design so that parts will not trap solutions and that they will drain easily when being put through the plating and finishing processes.

We will now go back for a minute to our poem about the designer and repeat the last two lines which read as follows: "He looked again and cried, "At last success is mine, it can't even be cast". This may be good for a laugh, but it is not as funny as it sounds. A heart to heart talk with a foundryman would bring to light some of the things that they are called upon to try to cast. I do not know of any item having but one operation in its manufacture such as has a casting that one will find as many rejects and poor parts produced. While, of course, many foundry rejects are the results of bad foundry practice, I am sure that most foundrymen will agree that the greatest cause for foundry rejects is the poor design of the parts being cast. The Production Engineer will check the part design for the factors necessary for producting a good casting and will consult with the foundryman and will if necessary, request changes from the Design Engineer.

Another factor encountered with castings is that the castings as cast are often difficult to machine because they cannot be easily held in turret lathes, mills or other machines.

The Production Engineer will consider the problem of holding the castings in jigs and machines and will if desirable, add a lug or a boss, to permit holding the piece while being machined. In many cases, this lug, or boss, can be used as a means of accumulating slag, or venting gas, which might otherwise get into the casting and produce a defective casting.

The Producion Engineer will also check the machined part when made from a casting and make sure that there is sufficient metal called for on all surfaces to be machined. In most cases, the Production Engineer will have a separate drawing made for the casting which will show only the dimensions required for producing the casting. This should be a must for all castings for several reasons.

First, it does not place the burden on the patternmaker of having to go over a complicated machine drawing to determine how much to allow for machining on any given surfaces. In most cases, the patternmaker is not familiar with the end use of the piece or the method to be used in machining it and the problem of allowing metal for finishing should not be left up to him. The Production Engineer, who is familiar with the end use of the product and the means available to machine it, is far better qualified to determine how much metal should be allowed for machining.

Many Design Engineers do not think it is necessary to have a separate casting drawing, or do not want to be bothered in making it. In fact, how often have we heard them say, "A casting drawing isn't necessary, the patternmaker knows where to allow for machining because the machined surfaces are shown on the finished part drawing." We know from sad experience, however, that the patternmaker does not always allow the proper amount for machining, in some cases allowing too much and in others too little. How often have those of us who have been up against this problem gone back to the patternmaker and complained because he has not allowed enough on a surface for machining only to hear him say, "I figured that you were not going to take a cut off of that surface, but were going to slick it on a belt so I didn't allow for machining. I made a similar part for Joe Doaks a while ago and he used a belt on a similar surface".

Or worse yet, the patternmaker allowed 3/32 inch for machining when we intended to slick the surface on a belt.

Other factors which influence the Production Engineer in calling for the making of a casting drawing are the following:

1) When the part drawing is given to the foundry for casting the only dimensions shown are those required for the actual production of the casting.
2) The same holds true for the patternmaker, as neither the foundryman or the patternmaker is confused with any of the machining dimensions.
3) It is much easier for the manufacturers inspec- tio tion department to inspect the castings to a casting drawing because there can be no controversy on the matter of machining allowances as the only dimensions being considered are those of the casting.

While on the subject of castings and machining allowances, it brings to mind a little story concerning an incident which was supposed to have taken place in a manufacturing plant. Obviously, the plant did not have a Production Engineer. The basis of this story is the well known fact that no design engineer ever likes to be told that he has made a mistake on a drawing.

It seems that one of the shop machinists walked into the designers office with a print under his arm and told the designer that there was a mistake in one dimension on the print. Without taking a look at the print, the designer somewhat peeved, told the machinist that the print had been thoroughly checked and there were no mistakes in it. He also told the machinist that, if the machinists as a group would devote a little more time to the study of the prints before starting a job, they would get a lot more work done and that they would not always be bothering the engineers with questions, the answers to which would be obvious if the print were more carefully studied. He then told the machinist to study the print more carefully and then go ahead and machine the piece.

The machinist left and about fifteen minutes later, returned to the designers office and dropped a handful of iron borings on the designers desk. The designer took a look at the pile of chips and asked the machinist what the big idea was. The machinist replied, "I took a very careful look at the drawing and then went ahead as you suggested. That pile of chips is the 1 1/8" hole which the drawing shows bored in the 1 1/16" boss on the drawing."

While a story such as this, may be good for a smile the very fact that someone thought about the condition that forms the basis of the story, it is not beyond the realm of possibility that it or something similar actually did happen. It is one of the functions of the Production Engineer to see that part drawings are in such a condition that incidents of this nature cannot occur.

Next, comes the matter of tooling and its relation to the product as designed. Very often the designer designs a product in such a manner that it cannot be produced efficiently on the equipment which the manufacturer has in his plant. This may be due to close limits as was previously mentioned, or to the fact that the manfacturers equipment will not produce the items at a low cost. The Production Engineer will make a careful study of the new item and knowing the limitations of the plants equipment will suggest the changes necessary to fit the new product to the present equipment. In the event that changes cannot be made in the product and new equipment is needed to produce the part, the Production Engineer will convince management of the necessity and will procure the required equipment.

In the matter of building tools, jigs and fixtures, often many thousands of dollars are spent in the construction of these items only to find that the tools will not produce parts to the accuracy called for on the drawings. When this occurs it often involves the additional expenditure of many thousands of dollars in an attempt to correct the tools. No good Production Engineer will knowingly permit tools, jigs or fixtures to be built when he knows that the parts limits are so close that the tools cannot be built to hold such close limits.

The aforementioned examples are quoted to indicate what can be expected from a competent Production Engineering Department. There are numerous other things that could be listed and which I may have overlooked, but I am sure that I have covered the more important ones.

I am afraid that we may have digressed too long in our discussion of our Design Engineer. Now, let's return to our lock case study.

As time passed, the Design Engineers made designs, the model makers made models and mockups which were submitted and resubmitted to management and finally one day a design was submitted which met with the requirements as set down. The design drawings were then turned over to the Production Engineering Department for checking of the various functions previously mentioned. Upon completion of the work of the Production Engineer the job was turned over to the tool Engineering Department who designed and built the necessary tools, dies, jigs and fixtures. In the due course of time, the new line of locks was in production and today we have the new lock which incorporates the various features originally laid down by management.

The case just cited covers a product which has been in production for about four years and is produced in a plant employing about 1200 people. Naturally, the work of Design Engineering, Production Engineering and Tool Engineering is the work of many people in separate departments. At this point, some of the smaller manufacturers may become afraid of the procedures outlined and say "this is not for me".

I would like to make it clear that the size of the organization, or the number of employees, has nothing to do with the application of Production Engineering. Production Engineering can be applied to the simplest product in the smallest plant as well as to the most complicated products in the larger plants. In applying Production Engineering, it does not mean that the smaller plants must have elaborate setups and separate departments staffed by separate groups of engineers.

It is very important, however, that if the small plant does decide to use Production Engineering and decides to combine the function with other engineering that they procure the services of competent engineers who are proficient in both of the engineering functions being combined.

The activities of the Production Engineer are not limited to the handling of new items being put into production, but they also cover the field of improvement on previously established methods and procedures. As an example of what can be accomplished along these lines by a good Production Engineering Department, I am quoting a couple of examples from one of a series of advertisements recently put out by the Curtiss-Wright Corporation, manufacturers of aircraft engines and equipment. "Through manufacturing Engineering the aircraft industry is progressively reducing cost and improving product and airplane performance. Some examples are:

1) A new process for extruding propeller blades from hot steel billets,
   - Increases blade strength
   - Cuts skilled manpower requirements
   - Eliminates costly machining
   - Saves strategic materials
   - Reduces manufacturing floor space.
2) A jet engine center section was originally an aluminum forging costing $5700.00.
   It is now produced as a ductile iron mild steel, casting and weldment costing about $1000.00. The new center section has superior properties permitting improved airplane performance."

Of course, it should go without saying that if a product is started out right there should be no need for the Production Engineer to have to go back over methods presently in use. However, such is not the case. There is much to be done on the correction of present methods and there will be for some years to come. During the war, when everything was in a hurry and plants and facilities had to be increased almost overnight, speed was the prime factor and not much attention was paid to cost or proper methods of doing things. Also, the shortage of competent Production Engineers caused some companies to by-pass the Production Engineering phase of the job. As a result of this, many evil practices crept into the manufacturing procedures and will have to be corrected when our economy levels off to a more or less normal condition. The Production Engineer is the one who will be called upon to remedy the present evil practices and to establish proper and profitable manufacturing procedures.

If a good job of Production Engineering is done on a product, it often makes the job of the Industrial Engineer easier. Many times the Industrial Engineer has to devote time to material handling, paper work or control problems in order to cut costs which would never have been incurred had the product been properly production engineered in the first place. Let us hope that in the future, some of the manufacturers in this area, who have been a little backward in the acceptance of Production Engineering in their manufacturing operations will come to recognize the value of this very important part of their organization. Only in this way will they be able to maintain their position in their respective markets against their more aggressive competition from this or other areas.

In conclusion, I would like to add to my own thoughts a few random quotes from an address titled "Dimensions and Tolerances for Mass Production" recently given in Los Angeles by Professor Earle Buckingham of the Mechanical Engineering Department of the Massachusetts Institute of Technology and author of many books among which are the nations outstanding books on Gear Design.

"The experimental engineering department is not in the best position to specify manufacturing requirements for mass production. A definite production design made by engineers familiar with the detailed problems of mass production is essential for mass production. If it is not made at the start, it will develop itself eventually by trial and error in the course of time in actual production. This last procedure is a time-wasting and costly method involving many changes and delays in production."

With these thoughts, I close and I thank you very kindly for your earnest attention.

TIME REDUCTION CURVES SESSION

Session Chairman: Charles A. Bogenrief, Los Angeles, February 2, 1953

TIME REDUCTION CURVES

H. W. Thue
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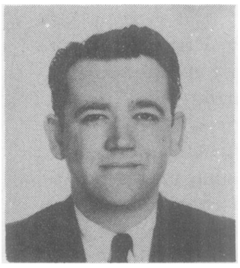


Our discussion today is going to deal with time reduction curves and the manufacturing industry. From the standpoint of production all manufacturing concerns will fall in one of three categories:

1. Good Producers
2. Marginal Producers
3. Sub-Marginal Producers

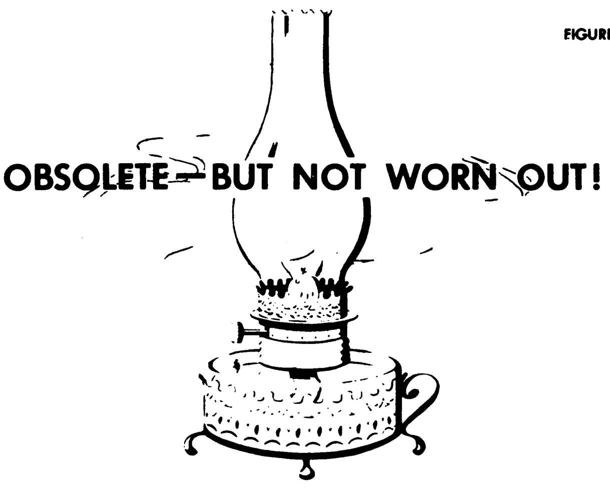
Where are you? Is your company a good or a marginal producer? If it's marginal how do you become better? If you are a good producer how can you still improve?

Our purpose is to demonstrate a management tool whereby sub-marginal and marginal producers can become good producers and the good producer can improve and make refinements to the degree that price and market considerations justify.

This reminds me of an advertisement I came across the other day that very cleverly put over the economic principles of American business. The ad showed a large kerosene lamp and was headlined----

"OBSOLETE---BUT NOT WORN OUT"

FIGURE 1



The text went something like this:

"More than 40 years old, this lamp is just as good as the day it was manufactured. It puts out as much light as it ever did. We could say that it's just as good as new. But would you want to light your home with it or with others like it?

"Here is a good example of what has made America prosperous-- we don't wait until something is worn out or breaks down. As soon as a better way is discovered and ready for the market, America buys it and puts it to work. Any machine or equipment is obsolete the moment something better--something that produces more or at a lower cost--is invented or developed. Using obsolete equipment until it wears out may be one of the biggest reasons why other countries fail to prosper."

To me this illustrates perfectly four basic essentials of successful business:

1. Desire for improvement
2. Free enterprise
3. Profitable enterprise
4. Supply and demand

FIGURE 2

FOUR BASIC ESSENTIALS OF SUCCESSFUL BUSINESS:

1. DESIRE FOR IMPROVEMENT

2. FREE ENTERPRISE

3. PROFITABLE ENTERPRISE

4. SUPPLY AND DEMAND

I believe that any time we have experienced economic difficulties it has been due to a violation of one or more of these principles. Whether it is a national or a managerial error the loss results from failure to observe the basic principles.

For example--does a glutted market mean that the economic system is wrong or does it mean that management has produced, maybe the right commodity, but at the wrong time? I feel it is the latter that is true.

Fundamentally sound business is based on good market analysis--public demand for the product!

Management must be:

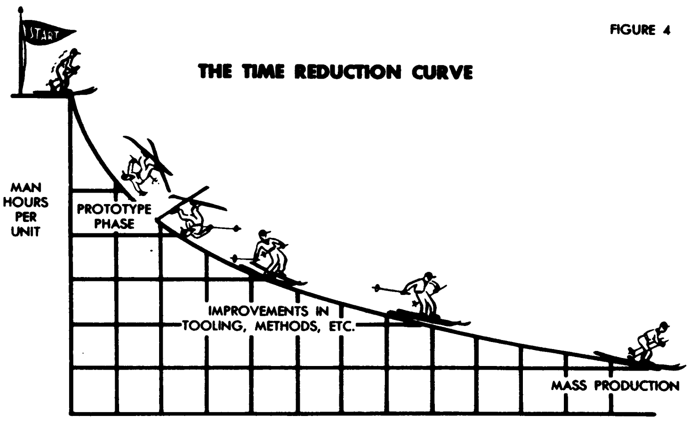
1. Farsighted enough to recognize the changes desired.
2. Clever enough to redesign its product.
3. Versatile enough to incorporate the changes in a moving production line.
4. Intelligent enough to plan, time and control the changes in relation to schedules and cost.

You probably wonder what a kerosene lamp and some general economic and managerial principles have to do with time reduction curves. It is very simple. They are the conditions. The techniques for the use of time reduction curves are the means by which the productive output can be calculated under these conditions.

MANAGEMENT MUST BE:

FIGURE 3

1. **FARSIGHTED ENOUGH TO RECOGNIZE THE CHANGES DESIRED**
2. **CLEVER ENOUGH TO REDESIGN ITS PRODUCT**
3. **VERSATILE ENOUGH TO INCORPORATE THE CHANGES IN A MOVING PRODUCTION LINE**
4. **INTELLIGENT ENOUGH TO PLAN, TIME AND CONTROL THE CHANGES IN RELATION TO SCHEDULES AND COST**



The knowledge and techniques we will speak about are neither an exact science nor are they purely in the realm of speculation and theory---they will produce results, which, when viewed in retrospect will be accurate within the limits that management controls the tangible factors and the intensity of the effect of the intangible factors. These techniques are not only applicable to the aircraft industry but can be applied to all manufactured units having repetitive operations.

Recognition of the need for a change is important, lest we find ourselves in the position of the manufacturer of kerosene lamps. Clever product design is essential too, in this fast moving age. The aircraft industry, like many other industries, offers many examples of last year's models that are obsolete because this year's designs are vastly superior.

And this year's designs are coming off the assembly lines this year because the best and latest changes have been successfully incorporated in moving production lines. The market is not glutted by obsolete products which are less than the best for their intended use. This is true because American industry has mastered to an amazing degree the techniques necessary to plan, time and control the changes to be incorporated.

It is with some of these techniques that we are concerned today. The degree with which we can master them and put them into practice will to a large extent determine our sales, our profits and our business success.

In a larger sense, it will determine the health of American industry and the strength of the American economy in its contest with foreign ideologies. Our challenge is to continuously improve our ability to produce the right things in the right quantity and at the right time. Our answer to this challenge is the development of managerial techniques for planning, timing and control that make such improvement possible.

Managerial problems are extremely complex. They cannot be solved by a simple formula, or by a graph or a chart. One of the most difficult aspects of managerial problems is the selection of pertinent information. If, from past experience and our mountain of records, we can select a few facts that apply to current problems of planning or timing or control, we are well on our way to a solution of those problems.

Let's look at some of this experience. Our particular concern is with the relationship between the number of units produced and the average working time per unit. We say "units" rather than "airplanes" or "refrigerators" or "television sets" because we are trying to discover a basic principle which applies to all repetitive production effort. What is a time reduction curve? Figure 4 shows the kind of improvement that comes with experience, either for skiing or for any time-consuming job.

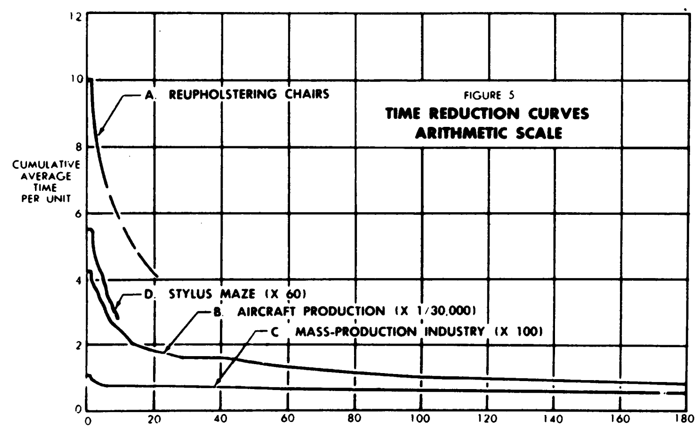
This is the curve that has sent many a worried manager back to the banker for more money. On about the third trip the banker realizes that the manager failed to appreciate the meaning of this curve and misjudged the cost of the first few units basing his calculations on previous experience of unit time at the 300th or 400th unit. As you can see, lack of understanding of this curve can result in:

1. Late delivery schedules
2. Missed market opportunities
3. Loss of profit
4. Bankruptcy

Everyday experience shows that two identical units of production are less than twice as much work as one unit. A friend of mine, knowing of my interest in this subject, recently reported his experience to me. He said that he had just finished the home-workshop job of re-upholstering three chairs. He reported ten hours' work the first weekend, and a production output of one chair. The following weekend brought his total work to 20 hours and his total production to 3 chairs, for an average of 6-2/3 hours per chair. The complete record for this job is shown by the short heavy line "A" on Figure 5.

This is a real example, not a fictitious one. Collect this type of data on your next home-workshop job, and see what pattern of time reduction it fits.

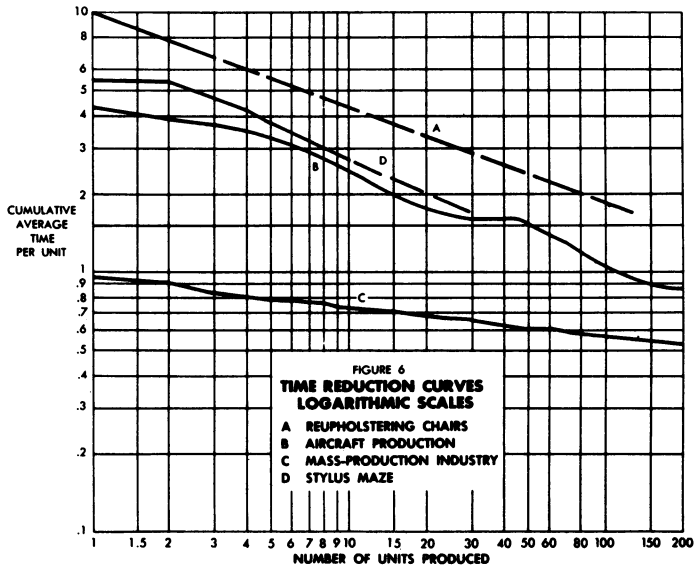
Shown also on Figure 5 are the records of widely different subjects, each on its own repetitive job. Line "B"



shows the cumulative average time per unit for a typical airplane. Note how it parallels the upholstery job.

One of many other industrial examples is shown in Line "C", the production report on the first 180 units of a job that eventually followed the time reduction curve for over 400,000 units.

Curve "D" shows time reduction on a widely different kind of repetitive job. It is the record of a psychology student who traced out a "stylus maze" several times. Considerable liberty has been taken with the vertical scale of Figure 5. Digits have been dropped or added as necessary to show all the examples on one page. The trend followed by all of the lines in Figure 5 seems to be a curve of the form "$Y = AX^b$". If this is true, all of the cruves should appear as straight lines on a log-log chart. That they do is shown by Figure 6. Note how the logarithmic scales help in comparison of the rate of time reduction for the several examples. Note also how easily curve "A" may be extrapolated along a straight line to predict the average hours per unit required to upholster 10, 50, or 200 chairs. This easy extrapolation is the characteristic that makes the time reduction curve valuable for such jobs as pricing, planning and cost control.



What are the reasons for time reduction? What are the factors affecting time per unit? The most obvious factor is the development of skill by the individual worker, or learning. In some cases this is so important that we sometimes speak of "learning curves". However, it is by no means the only factor involved.

Every element of the environment of a job has some effect on the rate of time reduction. Government regulation, labor laws and labor relations, customer requirements and even the weather are involved.

For instance, on a business trip to Mexico a couple of years ago I had occasion to observe the effects of labor law on production costs. Two automobile manufacturers have assembly plants in Mexico City. They were both concerned with a new labor law which stated that every employe who remained on the payroll for one year automatically became a permanent employe. Enforcement of this law would mean that, after one year of full-scale operations, employment could never be cut back during periods of low production. Here was a factor that threatened to add heavily to operating costs and unit man hours.

One firm chose to ignore the law on the assumption that it would never be enforced. The other firm shut down production on the normal cycle of annual re-tooling. It turned out that the law was enforced and the first firm experienced very high man hours per unit during their later period of low production.

This case illustrates not only the effect of labor laws on costs, but also the importance of managerial adjustments to such external factors.

It is of great interest to management that many of the factors contributing to time reduction are subject to management control. Some of these factors are:

1. Tooling - Manufacturing hours required to produce the first unit will depend to a large extent on the kind of tooling used. If schedules or budgets limit tooling to simple experimental type tools, manufacturing cost will be high. If more elaborate tooling can be made available during the initial production stages, the cost curve will be lowered and flattened; if better tooling is developed later in the production program, the time reduction curve will be steep. Management must determine the extent of the tooling program which will yield minimum total cost for tooling and manufacturing.
2. Plant Layout - Can often be improved with experience. The flow of work from one operation to the next will be speeded by relocating the operations. In addition, smoother geographic flow of work can be attained, in aircraft at least, by building up the production rate until all assembly line positions are occupied.
3. Greater use of power machinery. Initial units of a volume contract must often be turned out on general purpose machine tools in order to meet delivery schedules. Subsequent units however, will accommodate special purpose machines, more elaborate tooling, handling devices, or special materials. For instance a machined part may be hogged out of bar stock for the first three airplanes of a contract, but subsequent parts will be machined much more quickly from castings or forgings.
4. Improved methods and processes. A major factor in time reduction is the large number of improvements in methods and processes that become apparent through experience. A great variety of improvements will be presented by many contributors. Methods Engineers pay their way many times over by eliminating lost motions and simplifying production jobs. Process Engineers do likewise by developing ways to produce acceptable parts more quickly and cheaply. Important contributions in methods and processes come from shop employes, either through a formal employe suggestion plan or through individual initiative by a worker to improve his job. When production continues over an extended span of time, advancements in general technology provide improvements. For instance, many sheet metal parts of the DC-6 airplane were originally pre-formed on the Guerin Hydropress, then finished by expensive hand forming. Development of the Wheelon Press has made it possible to form these parts in one operation. Similar great time reductions have been realized on the same model through increasing use of high-speed carbide-tipped cutting tools.
5. Design for Production - Design changes must often be made to improve the product even though production time is increased thereby. However, design changes to facilitate production can be an important factor in time reduction. Some of these design

changes will be requested by Manufacturing or Tooling and others will be initiated by Engineering.

6. Coordination - Organizations learn in much the same way as individuals. Each of the above factors contributes to the learning of the production organization. Another important factor is the development of coordination, or team work. This improves with production experience because practice is necessary for individuals and groups to learn to work smoothly together. Experience provides for the development of smooth team work among workers (riveter and bucker are a good example), better coordination among supervisors and development of smoothly operating channels of communication and standardized procedures. Improvement in such indirect labor functions as paper flow and parts supply are often reflected in reduction of direct labor cost.

7. Management Policy - Decisions of management in regard to labor relations, working conditions, investment in inventories, introduction of new machines and processes and many other topics have a profound effect on the time reduction record. A policy of high risk will produce a different curve than a policy of low risk.

   A high risk policy is like trying to have a baby in six months. Normal time is nine months and the risk is too great to consider a shorter period of time.

   This topic also reminds me of the story of the hobo and the farmer. The hobo stopped by a farm house one day and asked for a handout. The farmer agreed to feed him if he would do some work. The first job was milking two cows which the hobo did in better than average time. The next chore was to hoe the weeds in the cabbage patch. This job was completed in well under the average time and seeing that the hobo was a better than average worker, the farmer told him he had one more chore for him. He took him down in the cellar and told him to sort a large pile of potatoes into three barrels, one was for the spoiled potatoes, one for the sprouts and the third was for the good potatoes.

   After a considerable length of time the farmer went back to check on the hobo's progress and to his surprise he had only segregated about five potatoes. When the farmer expressed his surprise at the small amount of progress made after the excellent time he had made on the other jobs the hobo looked up with a pained look on his face and said, "It isn't the work it's the decisions that are killing me!"

General Management policy will affect the level of the time reduction curve while a change in management policy will affect the slope of the curve.

8. Training - The fundamental problem on training time is whether it should be included in the time for each unit or charged to burden. It is not important which course you adopt, as long as you know exactly what amount of on-the-job training, if any, is included in your reports of unit hours. Inclusion of training time in your cost reduction curves will raise them, and it will also pinpoint information on training costs incident to expansion or changes. However, if change in unit time is caused by a revision of cost accounting classification of training time or other factors, this change of the ground rules should be made known to all who will use the data.

9. Rate of production - There seems to be an optimum rate of production for each set of operating conditions, just as there is an optimum speed for driving down Wilshire Boulevard. When signal lights are set to pass traffic at 30 miles per hour, it is difficult and perhaps risky to try to travel at a different speed. Similarly, to realize a satisfactory reduction of unit time an appropriate rate of production must be maintained. Costs will be high and they will stay high when a production schedule is accelerated too rapidly. Lack of continuity in a production program will certainly result in increased hours per unit, because carry-over of skill and coordination is never 100%. These and other factors affect the rate of time reduction. Variations in these factors will produce deviations from the smooth time reduction curve. Managerial planning attempts to predict these variations, and managerial control attempts to shape them to plan.

FACTORS CONTRIBUTING TO TIME REDUCTION

FIGURE 7

1. TOOLING
2. PLANT LAYOUT
3. SPECIAL MACHINERY
4. IMPROVED METHODS AND PROCESSES
5. DESIGN FOR PRODUCTION
6. COORDINATION
7. MANAGEMENT POLICY
8. TRAINING
9. RATE OF PRODUCTION

The time reduction function is important to American industry because it provides an objective measure of the pulse of the industrial machine against a standard that requires continuous improvement. It challenges industry to produce more for less; to strive to surpass whatever production achievements have been made in the past. That we have accepted the challenge is indicated by the fact that the productivity of American industry is now at the highest level in history.

The importance of the time reduction curve to the management of an industrial firm is two-fold. First, the very existence of the function is an incentive to a large scale production. It means that average unit labor cost is reduced every time another unit is produced. This along with wider amortization of tooling and development costs encourages the manufacturer to produce more and sell more. It leads to advertising, promotion and expansion.

Second, recognition of the existence of the time reduction curve and of its form is a powerful tool for planning and control of industrial production. It does an important job in cost estimating, shop loading, scheduling, and control of shop labor cost. These and other applications in the aircraft industry will be explained and illustrated in Part Three of this discussion by Mr. Shappell.

The form of the time reduction curve and the construction of representative curves will be described in Part Two by Mr. Maynard.

MATHEMATICAL THEORY OF TIME REDUCTION CURVES

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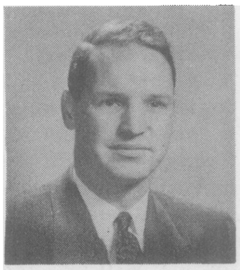
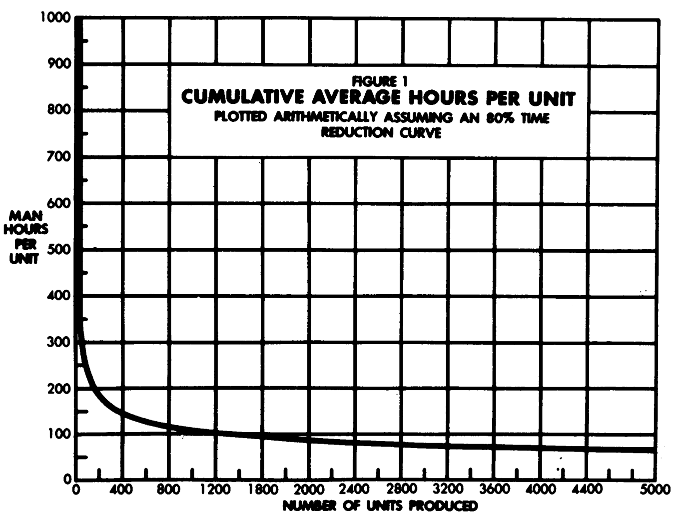


It is not intended that this presentation be along rigorous mathematical lines. In fact, certain liberties have been taken in the terminology. Nor will you learn anything any more unique or startling than in a 20-minute discussion on the mathematics of simple linear correlation. Time reduction curves are a tool used widely in the airframe industry and the general concept you will find to be fairly elementary. Except for the formulas which are footnoted, the majority of the discussion will be a graphical presentation, rather than algebraic.

I prefer the graphical treatment since the time reduction curve is a statistically derived curve from actual data. In fact, this is an important point to bear in mind throughout. The fact that the curve is derived from statistical data of a certain degree of dispersion means that it not only is a line of best fit or an average trend line but that even the shape of the curve, or the equation chosen, is up to the discretion of the statistician. I shall start by assuming that the data best fits an equation of one particular type.

Ordinarily, due to the type of equation of the curve, the data and the curve are plotted on graph paper having logarithmic grids for both the x and y axes. However, since it is difficult to think in geometric progressions, I would like to show the equation plotted on arithmetic graph paper.

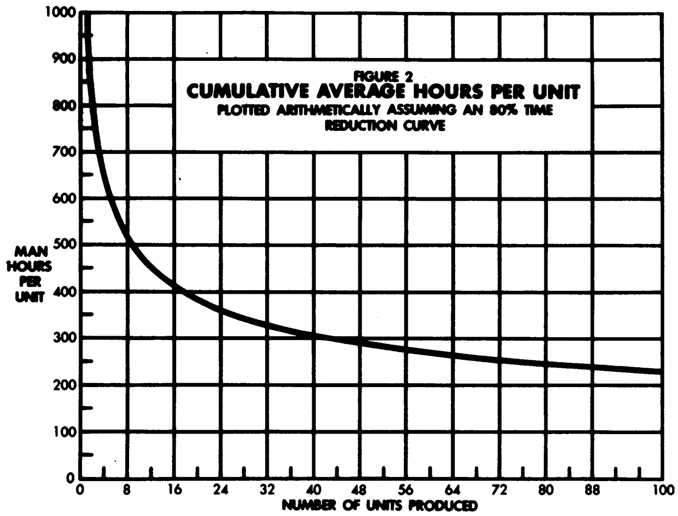
The y axis represents hours per unit, the x axis the number of units produced.



As you see from figure 1, the time per unit drops very rapidly out to the 1000th or 2000th unit and then levels off and, from a quick glance, it appears that the time per unit almost ceases to reduce.

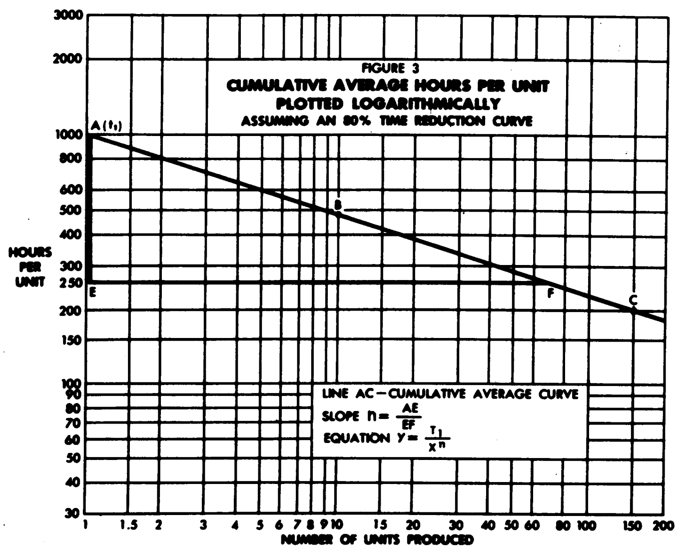
Figure 2 is an enlarged portion of the curve from the 1st through the 100th unit.

It is fairly apparent, I believe, that if one had actual data for the early or first units, it would be difficult to fit a curve, and even more difficult would be the problem of choosing the type of equation.



On logarithmic paper this same curve of figure 1 becomes the straight line A C of figure 3. This curve is identified in several ways. It is sometimes referred to as an 80% curve or as a curve of .322 slope or a .678 curve. You will note that if we assume the data follows a linear trend, even though on double logarithmic paper, one has a simpler job of fitting a curve to the data since it is only a matter of using a straight edge.

The straight line A C in figure 3 is representative of the cumulative average hours per unit for any given number of units. That is, point B is the average time per unit of the first 10 units. Point C is the average of the first 150

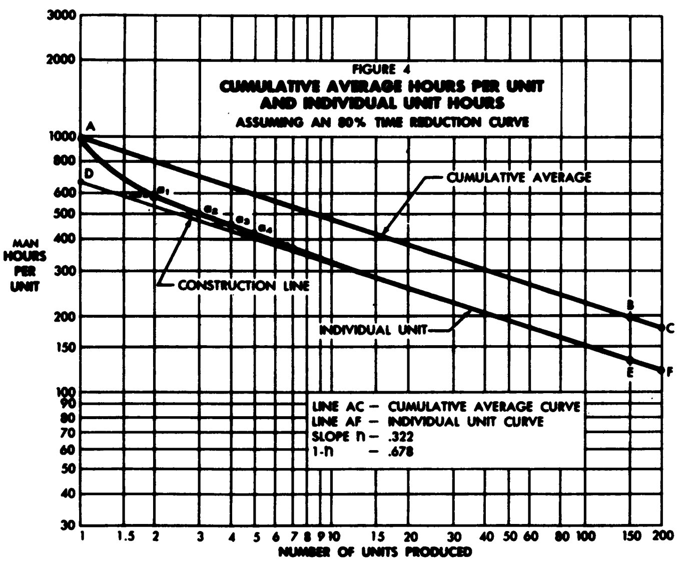


units, etc. Point A, the time of the first unit, will be designated as t_1. The equation of this line is $Y = \frac{t_1}{X^n}$. The value of n is referred to as the slope and is the ratio of the distance A E divided by E F, both measured arithmetically. In this particular case, n has a value of .322. The value of the slope then is one way of identifying the curve.

The assumption that the cumulative average hours per unit plotted against the number of units is a straight line on logarithmic paper is the basic premise and all the rest of the mathematics is based on this. Naturally, if the data does not appear to be linear on logarithmic paper, another curve must be chosen and the subsequent mathematics altered accordingly.

I mentioned that this is also called an 80% curve. The reason for this is that whenever the number of units are doubled, the cumulative hours per unit are 80% of the previous average. That is, referring to figure 3, the value at unit 2 is 800, or 80% of the first unit, which is 1000. The value at unit 150 is 200 or 80% of the value at the 75th unit, which is 250. Similarly a 90% curve is one where, when the number of units are doubled, the resulting hours per unit are 90% of the previous hours per unit.

So far all of my remarks have pertained to the cumulative average curve. A second curve that is required for estimating purposes is the individual unit curve. The curve discussed so far tells us the cumulative average hours per unit for any cumulative units. It is also necessary to have a theoretical curve that gives us the time for any particular unit. In figure 4, A C is the same cumulative average curve as A C in figure 3. Without going through the mathematics involved, this individual unit curve will look like the curve A F in figure 4.



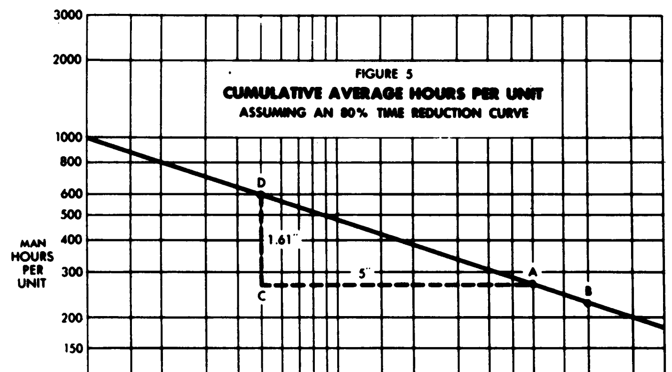
In order to determine the individual unit line, graphically lay off a point on the y axis whose value is .678 of t_1. The value, .678 is derived from subtracting the value of the slope, .322 from 1.000. This is point D in figure 4. Through this point draw a line parallel to A C. This gives the construction line. Read from this line points at X = 1-1/2, 2-1/2, 3-1/2, etc. and plot them at 2, 3, 4, etc. These are the points a_1, a_2, a_3, a_4. In other words, move the construction line 1/2 unit to the right. This gives the curve A F by fairing these points back in a curve to t_1 or A.

As you will notice, after about 10 or 20 units, the effect of moving the construction line 1/2 unit to the right is hardly distinguishable. Hence, for all practical purposes the time for an individual unit is .678 times the cumulative average of the units after 10 or 20 units. Conversely, given the hours for say, the 100th unit, the average of the first 100 units may be derived by dividing by .678.

For example, the cumulative average for the first 150 units is 200 hours (point B). The time for the 150th unit is 135.6 hours (point E) or .678 times 200.

With this brief introduction as to the relationship of the cumulative average curve and the individual unit curve, I would like to spend the few remaining minutes on the development of these two curves for 3 particular cases.

First - let us consider the case where we have the total hours for, let us say, the first 50 units. We are now faced with a single point, namely, the total for 50 units from which we can derive the average of the first 50 units by simple division. This average value is plotted at 50 units - point A on figure 5. We must assume a slope and, if we have no other knowledge, we can use an 80% curve or a .322 slope. Two methods may be used. To construct the cumulative average line, we can plot a point B, at 100 units, where 100 is the double of 50 units and, hence, the ordinate, or y value, will be 80% of the value at point A or 50 units and draw a line connecting the two. Or, we can measure A C an arbitrary distance, say 5 inches and up to point D where C D will be such that C D divided by A C will be .322. Thus C D must be 1.61 inches since 1.61 divided by 5 is .322, the slope of an 80% curve. Now a line through A D will be the same as the line through A B. It is usually more accurate to use the latter method.



Once the cumulative average line is determined we can draw the individual unit line, or figure individual unit points as per figure 4.

The second problem is one in which we are given the time for a particular unit, say the 150th itself, instead of the average of the first 150. The first step is similar to that in figure 5 and in fact identical if the individual unit point is for a point after the 10th or 20th unit. Through the time for the 150th unit (point E in figure 4) we construct a straight line with slope of .322 or an 80% slope. This will be done as before and will be the construction line D F of figure 4. To determine the cumulative average curve, we construct a line parallel to the construction line through a point that is 1.475 times the values of the individual unit line, where 1.475 is 1/.678 and .678 is 1.000 less the slope, .322. This gives the line A C of figure 4. Now having the construction line and the cumulative average line the individual unit line will be constructed as before.

The third case I would like to discuss is the one which is met most often in estimating. Let us now take the case of having been given several points. Consider the six points, A, B, C, D, E, F, of figure 6. All of these are the actuals for various number of units. That is, A is the time for the 21st unit, B the time for the 29th unit, etc. These are not the cumulative average times but the individual unit times. Be sure you understand the difference between these two. We can now do one of two things. We can still insist that this data conforms to an 80% curve or we can fit, by any method you wish to choose, a line of best fit to these actuals. I am certain that all of you appreciate that statistics is merely a tool for analysis and that the analysis must be more than merely applying various mathematical concepts, or setting up a series of simultaneous equations, obtaining a solution and going no further. Before any further step was taken, you would want to ask a good many questions about the data. However, let us assume that we have gone into these questions and have agreed to fit, by eye, a line of best fit.

This results in the line K M. (If one wishes to fit an 80% curve, the problem is really a special case of the preceding problem where a point on the individual unit line and a fixed slope is given.) We now determine the slope of this line which will be the ratio of L M to K L which in the case of figure 6 is 5 inches divided by 1.38 inches or .275. We now draw a line parallel to K M so that the values on this new line, P Q, are 1.38 the values of the points on line K M, where 1.38 is 1/.725, and .725 is 1.000 less the slope of .275.

We now have a cumulative average curve for all units given 6 individual points.

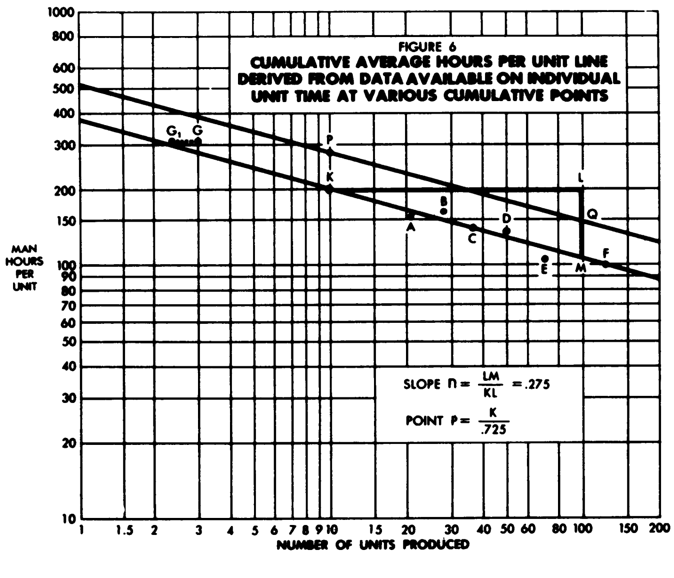


FIGURE 6
CUMULATIVE AVERAGE HOURS PER UNIT LINE DERIVED FROM DATA AVAILABLE ON INDIVIDUAL UNIT TIME AT VARIOUS CUMULATIVE POINTS

I have purposely avoided a discussion of the area from unit one to 20 on these last two examples. I believe you will realize that what we do when we fit a line to the individual unit points is to determine the construction line and not the individual unit line. One needs to remember that all individual unit points should be plotted 1/2 unit to the left before fitting a curve if the points are for the unit 20 or less. For example, if a seventh point, G, the time for the third unit were given, it would be plotted at the 3rd unit. However, for the purpose of determining the construction line K M, the point G would be moved 1/2 unit to the left and plotted as point G_1 at unit 2-1/2. When the individual unit line was constructed from line K M, point G would be in the same relationship to the individual unit line as the point G_1 is to the construction line.

From an understanding of the three cases discussed, I believe you will find it possible to handle most any other case that might arise. Footnoted below are the algebraic relationships which will help to follow the reasons for the various steps used in construction.

In conclusion I would like to re-emphasize the fact that the time reduction curve is an equation determined empirically from actual experience using standard statistical techniques and is subject to the same limitations and qualifications as any statistically determined function.

SYMBOLS AND EQUATIONS FOR TIME REDUCTION CURVES

x = number units produced

A_x = cumulative average hours per unit for the first x units

t_x = hours per unit for the x^{th} unit

t_1 = hours for the first unit. (Although $A_1 = t_1$, the symbol t_1 is usually used.)

n = slope of cumulative average line and/or the construction line for the individual unit line.

n expressed as a percent = (1/2) n (100%)

eg. (1/2) .322 (100%) = 80%

$$A_x = \frac{t_1}{Xn}$$

Expressed as a logarithmic equation, $\log A_x = \log t_1 - n \log x$

Three equations are available for the individual unit time, with qualifications as noted:

1. $t_x = xA_x - (x-1)\, A_{x-1} = t_1 \left(x^{1-n} - (x-1)^{1-n}\right)$

   This equation is exact and was not discussed in the presentation.

2. $$t_x = \frac{(1-n)t_1}{(x-.5)^n}$$

   This equation is an approximation only for $x>1$, but is sufficiently accurate for most work.

3. $$t_x = \frac{(1-n)t_1}{x^n} = (1-n)\, A_x$$

   This equation is less accurate than (2) but is sufficiently accurate for most work if $x > 20$. This is actually the equation of the construction line.

In all of the above equations n, the slope, is expressed as the absolute value. Actually the slope is negative since for increasing values of x, y is decreasing.

PRODUCTION APPLICATION OF TIME REDUCTION CURVES

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You have heard about time reduction curves and the mathematics of time reduction curves. I shall discuss some of the production applications that have proved useful at Douglas Aircraft Company. However, as with many simple formulas, there is more to the subject than meets the eye. Just as the knowledge that 2 plus 2 equals 4 does not make a **mathematician,** so a nodding acquaintance with the time reduction function is not sufficient qualification to attempt its use in solving production problems.

I do not mean to discourage potential users of the time reduction curve. However, I caution them to expect little of this tool until its applicability to their problems has been proved. Furthermore, potential users would do well to weigh many of the numerical values developed in the aircraft industry, and try rather to develop a knowledge of the slope of time reduction that can be expected in their own factories.

I believe that the following applications of time reduction curves will be generally useful. That is, they will not be confined to use in the aircraft industry.

The earliest application of the time reduction curve was estimating cumulative average time for a new model, in advance of production. Cumulative average time is an important element in estimating average unit cost and sales price. An actual case will be very complicated, but a simplified example will illustrate the principles involved. The required information will be: 1. The value of t_1. This is the estimated labor hours required to produce the first unit. 2. The expected slope of the time reduction curve. In the absence of other data, we will assume a slope that is typical of our past experience, say 80%. 3. The number of units to be built.

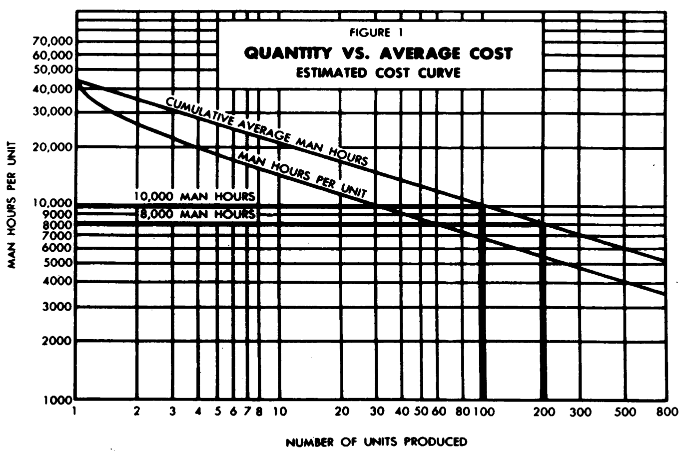

FIGURE 1
QUANTITY VS. AVERAGE COST
ESTIMATED COST CURVE

With these data we can construct a time reduction curve, using the method Mr. Maynard outlined in connection with his Figure 6. A sample case is shown in Figure 1. The first-airplane estimate is 44,100 hours of production labor. However, the cumulative average cost to Unit #100 will be only 10,000 hours. Therefore, if we can sell 100 airplanes, the constant sales price need only be enough to correspond to this cost. Note also that if we can build and sell 200 airplanes the manufacturing labor cost (on an 80% curve) will be 80% of the cost for 100 airplanes, and the sales price can be reduced accordingly.

The first estimate will give a good approximation to actual manufacturing costs for any number of units. Then, after the first few units are completed, it will be necessary to check actual cost against the estimate, and to revise the latter as more information becomes available.

An actual case is shown in Figure 2. Production of this project began at a cost of something over 50,000 hours per unit, but by the time the tenth unit had been delivered the unit time had been reduced to one-third of the time for the first unit, and it became apparent that the project was actually realizing time reductions at the rate of an 80% time reduction.

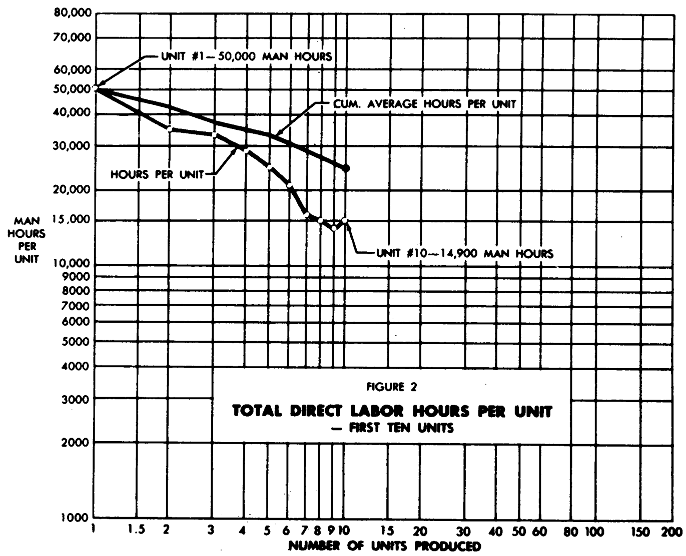

FIGURE 2
TOTAL DIRECT LABOR HOURS PER UNIT
— FIRST TEN UNITS

Figure 3 shows this same case as shown in Figure 2 through the first 10 units. The straight line of 80% slope can now be drawn through the cumulative average time to unit number 10, and extended to any desired number of units.

On Figure 4 the same data is shown as on Figure 3 plus the actuals extended through unit #200. While the times for individual airplanes varied widely due to changing production conditions, the cumulative average time followed the prediction line with fair accuracy.

In addition to pricing, the time reduction curve for a whole airplane is valuable for long range planning. For instance, if it is desired to build one airplane per day, beginning at unit #80, the curve shows that 8,000 hours per day, or 1,000 production workers, will be necessary. Plans must be made to hire and train this number of workers, or if this does not seem possible, production schedules must be revised. Since plans for facilities, machinery, manpower and materials all depend upon cost per unit and the scheduled production rate, a time reduction curve of usable accuracy is a fundamental requirement.

All of my remarks so far have concerned the time reduction curve for a total project, such as an airplane. In order to illustrate further applications of cost reduc-

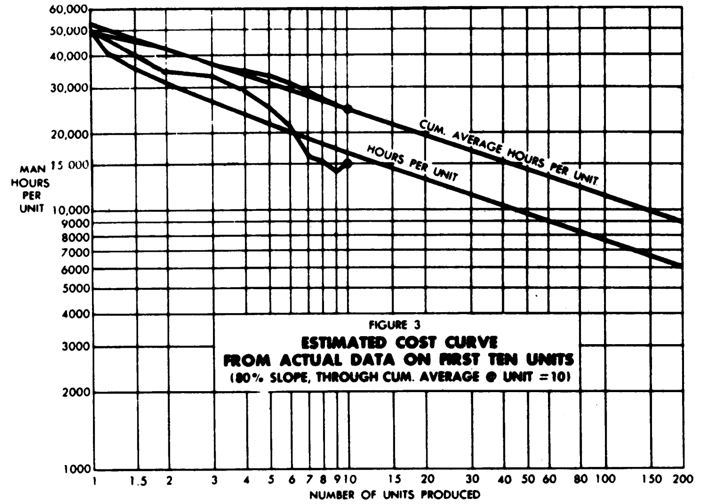

FIGURE 3
ESTIMATED COST CURVE
FROM ACTUAL DATA ON FIRST TEN UNITS
(80% SLOPE, THROUGH CUM. AVERAGE @ UNIT = 10)

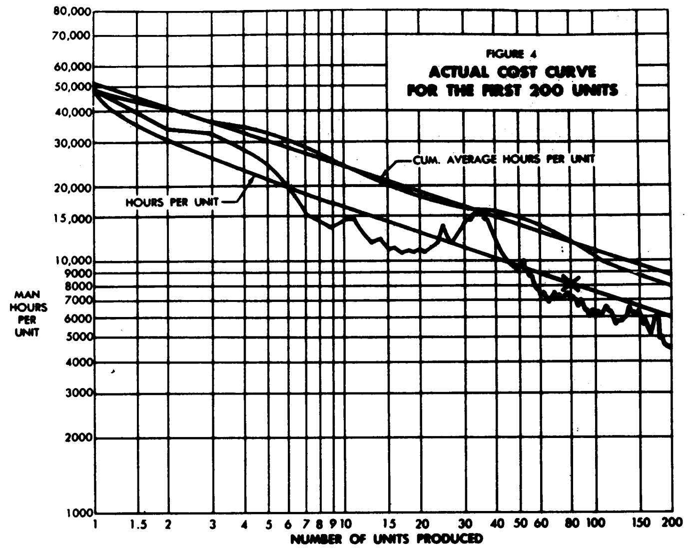

FIGURE 4
ACTUAL COST CURVE
FOR THE FIRST 200 UNITS

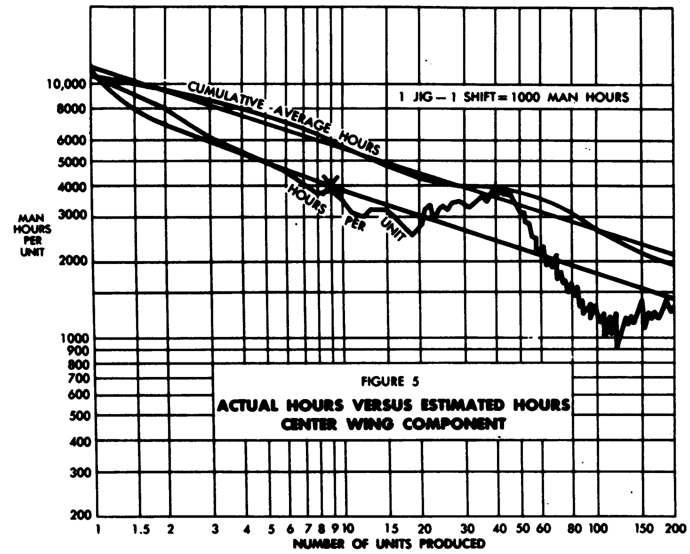

FIGURE 5
ACTUAL HOURS VERSUS ESTIMATED HOURS
CENTER WING COMPONENT

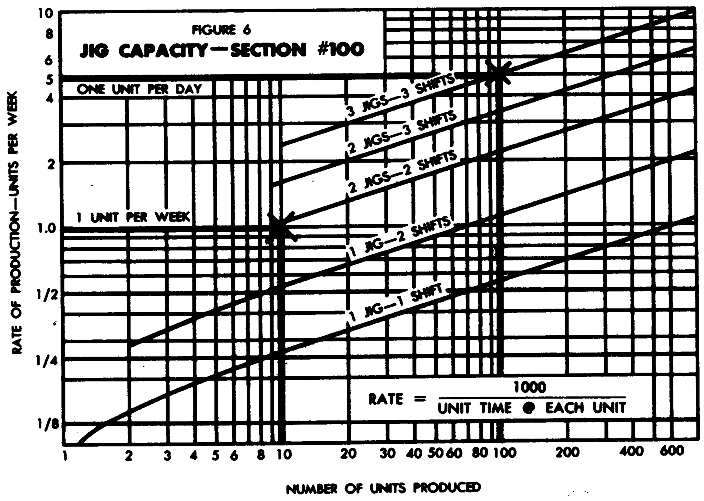

FIGURE 6
JIG CAPACITY—SECTION #100

tion curves, it will be necessary to introduce the idea that the curve for a total project is the sum of the curves for its several parts.

A breakdown of production time will permit the construction of a time reduction curve for each assembly job. The estimating curve and subsequent performance for a representative wing section are shown on Figure 5. This job consists of a major structural assembly. It is assembled in one jig. Maximum personnel for efficient operation is 25 men, or 1,000 manhours per week, for one shift. For example, at Unit #9, the unit time is 4,000 hours. Therefore, an elapsed time of four weeks will be required, on one shift operation.

To determine the capacity of this jig at any point on the time reduction curve, simply divide the numerical values by 1,000. The result is number of weeks' work per airplane. Inverting these figures gives

$$\text{Rate} = \frac{1000}{\text{Unit time @ each unit}}$$

the number of sections that can be expected weekly from each shift, with one jig. This is shown on the jig capacity chart (Figure 6) along with similar expectations for two and three-shift operation and two or three jigs.

General schedule requirements will determine the number of jigs that must ultimately be used. For instance, one unit per week, beginning at unit number 10, calls for two jigs and two shifts. One unit per day, beginning at unit #100, requires three jigs, used on three shifts. Other schedule requirements may be spotted in on the chart of jig capacity. This determines the number of jigs required and also determines a delivery schedule for the jigs. This same principle can be applied to either jigs, line positions, or work stations, and will serve as an aid in determining plant area requirements.

From the point of view of managerial control, this device has several values. Not only does it establish a schedule for tooling and area requirements, but it does this at a very early stage in the production program. This allows time to check the production and tooling schedules for practicability, and to adjust the production schedule as necessary to accomodate the tooling and plant layout program.

After a schedule has been determined, another application of time reduction curve data is the construction of estimates of manpower requirements. I avoided a discussion of this subject in the case of a total airplane, because the techniques in that case are rather complicated. However, for a single jig the job is relatively simple. Schedule requirements may be shown by plotting consecutive units against their respective due dates. This usually results in a curve like Figure 7. The elapsed time allowed by this schedule will be shown for each unit. For instance, unit number 2 can be put into the jig as soon as number 1 is completed. It is due out of the jig four weeks later. The time reduction curve has shown that 7,000 hours of work must be accomplished during that four weeks. The manpower requirements for this unit are then determined, as shown, by

$$\text{Average manpower} = \frac{\text{Estimated Man Hours Per Unit}}{\text{Elapsed Weeks x 40}}$$

or

$$\frac{7000}{4 \times 40} = 43.75 \text{ or } 44 \text{ men}$$

Similar calculations will show the manpower requirements for other representative units, for instance numbers 12, 13 and 14 as shown in Figure 7.

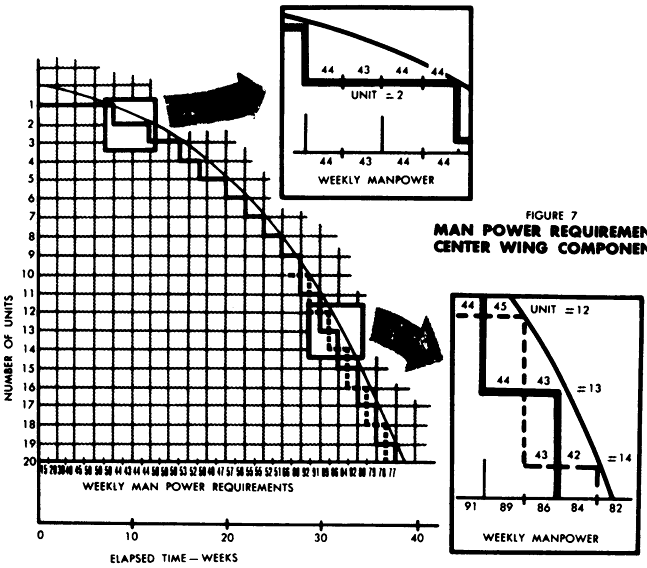

FIGURE 7
MAN POWER REQUIREMENTS CENTER WING COMPONENTS

Unit #13 will be built in the original jig, and unit #14 will follow #12 in the second jig. Total manpower requirements for the job will equal the sum of the men required on both jigs at a given time. The requirements for each particular week are shown next to the date strip at the bottom of the chart. For instance, Unit #13 is scheduled into the assembly jig on week #30, and total manpower required that week on both jigs is 89 men. This same analysis may be applied to any number of jigs, line positions or work stations.

The calculated manpower requirements can then be faired into a smooth curve. Final personnel loading will be adjusted to conform to production schedule, tooling schedule and reasonable rate of dilution of the trained labor force.

One of the most difficult problems of production management is incorporation of design changes in an active production line. After the need for a product improvement has been determined, and the design change has been created, the new design must be introduced into the production line. To do this at minimum cost and in minimum elapsed time requires careful planning and diligent control. To accomplish the change without disruption or delay of the entire production program is even more important - and more difficult. It is seldom possible to shut down a whole factory while assembly space is cleared for the new job and the final assembly line is rearranged to accomodate installation of the new assembly. On the contrary, it is usually necessary to maintain production rates during the changeover.

An example will illustrate some of the problems involved and some of the methods of solution. Let us assume that the unit we have been discussing is an airplane outer wing in production at a constant rate of one unit per week. It is desired to introduce a change, for instance, a new plastic wing tip, to be installed on all units subsequent to number 50.

Our first concern is the magnitude of the job, so we estimate the job and project it on an 80% time reduction curve, as is shown on Figure 8. The estimate at Unit #200 is 123 hours per assembly, but the time reduction curve shows that the first plastic wing tip can be expected to cost about 1,000 hours of assembly labor. Only one man can work on this jig, therefore utilization would equal 120 manhours per week on a three-shift basis. From this simple relationship, many problems of planning and scheduling can be solved.

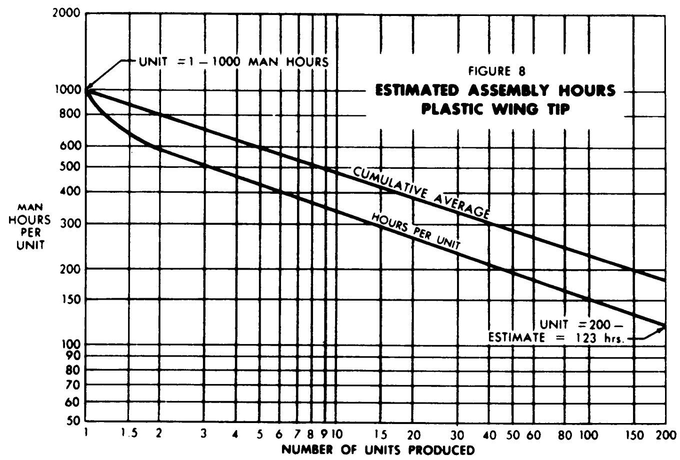

FIGURE 8
ESTIMATED ASSEMBLY HOURS PLASTIC WING TIP

With this information, we can establish a jig capacity chart as shown on Figure 9. This indicates that the first unit cannot be assembled in less than eight weeks. Furthermore, one jig cannot produce at the desired rate of one per week until about unit number 200. Therefore, at least two jigs will be required. Two jigs, operating three shifts, will provide delivery at the required rate, beginning at about wing tip number 25.

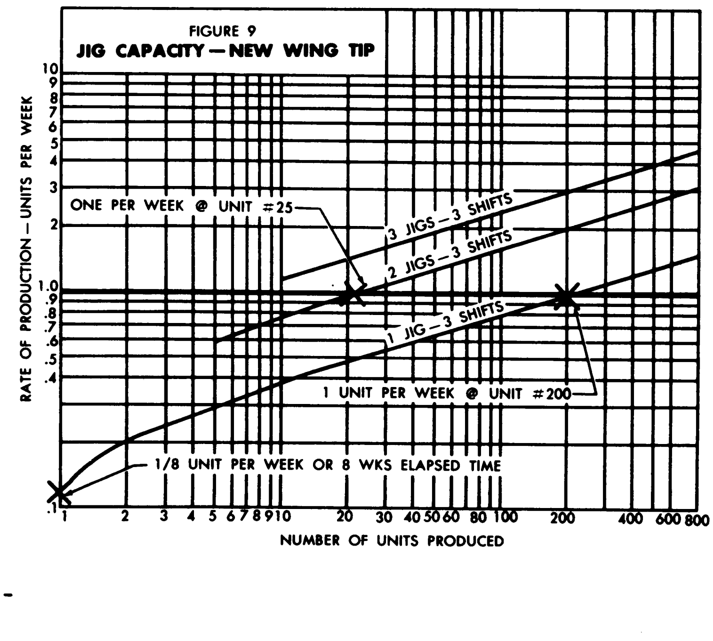

FIGURE 9
JIG CAPACITY — NEW WING TIP

Having ascertained this, the rate of acceleration and the production schedule for the new assembly can now be determined as is shown in Figure 10. Rate of production will be limited to the capacity of two jigs. As we have seen, this rate will not equal the rate of usage until unit #25. Therefore, wing tips #1 through #24 must be built ahead and stored. A point-by-point analysis shows that the first wing tip (unit #1) must be completed at least 20 weeks before it is used, in order to allow sufficient elapsed time to complete the next 24 units. The resulting production schedule for the new wing tip is shown by a shaded area. The lefthand edge defines the starting date for each assembly, and the right-hand edge the required completion date. Each unit must clear its jig according to this schedule in order to allow the next unit to start.

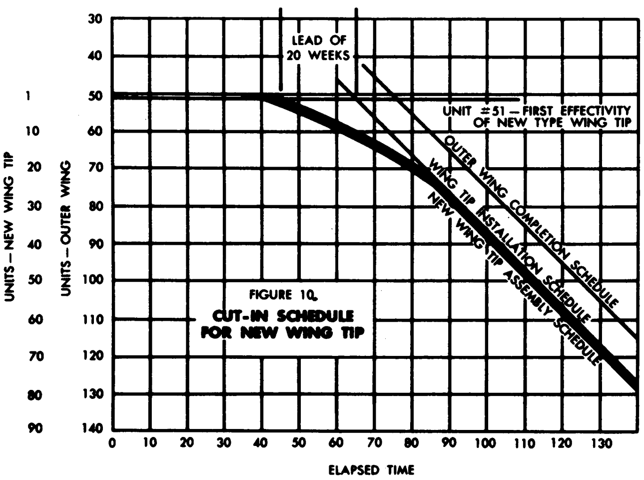

FIGURE 10. CUT-IN SCHEDULE FOR NEW WING TIP

Several other production problems may be solved by reference to this schedule. For instance, some problems are illustrated in **Figure 11**:

1. The required date for start of assembly may now be coordinated with known flow times for engineering design, tooling design and construction, material procurement and parts fabrication. The permissible overlap of these flow times will be known or estimated. The result of these comparisons will be the determination of the latest date on which engineering design can begin. Sometimes it turns out that this date is already past, in which case special action must be taken at once. More than two wing tip jigs may have to be used, or special measures may be taken to shorten the flow time, such as overtime or experimental-type fabrication without tools for the first few units, or the effectivity of the change may be delayed beyond wing number 51.
2. Production of the original wing tip must be continued through wing #50. Normally this would mean that factory space and personnel would have to be provided for simultaneous production of both old and new assemblies. The overlap in this instance is shown to be 30 weeks. If this is not desirable steps must be taken to provide the required 50 sets of old-type wing tips at an earlier date.

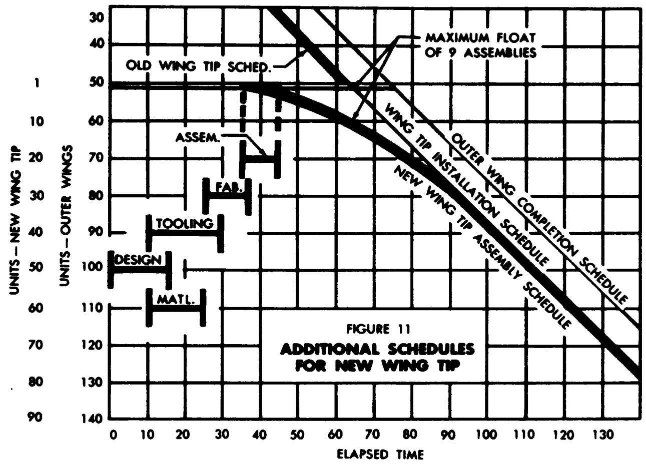

FIGURE 11 ADDITIONAL SCHEDULES FOR NEW WING TIP

3. The derived schedule requires that nine of the new assemblies be built and stored before the first one is used. Storage space must be provided.

In the matter of control, the time reduction curve offers valuable assistance in its comparison of results with plans. Deviations from original plans will occur in amount of manpower available and in performance. These will produce deviations from the original schedule and cost estimates unless corrective control measures are applied.

Time does not permit a discussion of other uses of the time reduction curve, such as estimating prototype manufacturing time for a new model, or estimating space and facilities requirements for a complete production program. Many other applications are being developed as a result of the growing use of the time reduction curve in general industry as well as in aircraft production.

I would like to close with a word of caution about the limitations of the time reduction curve as a tool for planning and control.

The time reduction curve is a statistical expression. It is a line of best fit for actual data. Actual times will seldom equal the theoretical value, but all will be more or less closely distributed around the trend line. It is necessary to remember this lest we make applications of the plotted values that are not warranted by their accuracy.

It is necessary also to determine the correct slope of a working curve. As we have shown, estimating experience will do this for an estimate of a future project; and experience on the first few units will predict the slope of the time reduction curve for subsequent units of a current project.

A small investment in collection of cost data and plotting of curves will yield large returns in better planning, timing and control of production. Our experience has proved that time reduction information is useful for:

1. Pricing of product.
2. Jig requirements, both as to quantity and schedule.
3. Multiple or single shift requirements and timing of same.
4. Area requirements (how much and when).
5. Manufacturing schedules.
6. Manpower requirements.
7. Incorporation of design changes in an active production program.

I believe industry in general will continue to find new and profitable applications for this device.

RESULTS OF RESEARCH
IN INDUSTRIAL ENGINEERING SESSION

Session Chairmen: H. A. Schade, Berkeley, January 30, 1953
J. F. Manildi, Los Angeles, February 3, 1953

VISUAL INSPECTION FOR SURFACE DEFECTS

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At the past two Institutes you have heard Mr. A. L. DeHart and Mr. Alex Rossi present some of the preliminary results of studies which were initiated over three years ago in order to ascertain the optimum conditions for visual inspection for surface defects on objects which were moving on a conveyor belt past an inspector. During the past year this project has been carried to completion under the sponsorship of the United States Department of Agriculture. The complete results of this project will be published soon by the Department of Agriculture. It is my purpose here merely to present verbally some of the primary conclusions which resulted from this project and to show by means of a motion picture* the way in which this work was carried out in the laboratory and in field tests conducted in actual fruit and vegetable packing houses.

The conclusions which resulted from the project may be stated briefly as follows:

1. In inspecting objects for defects located on a peripheral surface the speed of rotation of the object, while being moved in translation, is a primary factor in determining inspection efficiency. For cylindrical and ellipsoidal specimens, which tend to roll about one axis, they should be rotated at least 3/4 revolutions per foot of translation per row of objects presented for simultaneous inspection. For spheroidal specimens, which roll about numerous axes, a rotational speed of about 1.6 revolutions per foot appears to be most satisfactory when from 3 to 5 rows are presented for simultaneous inspection.

2. Forward rotation (so that the motion of the top of the object is in the same direction as the translational motion) is desirable in order to avoid "belt sickness" which occurs when certain speeds of backward rotation are used.

3. Direct presentation of the specimens (specimens moving directly toward the inspector) gives superior results to side presentation for nearly all cases.

4. The presentation of specimens at regular intervals along the inspection belt is much better than haphazard spacing, both from inspection efficiency and operator satisfaction.

5. When side presentation of specimens is used most inspectors seem to prefer that the specimens move right to left rather than from left to right. This apparently has no connection with whether the inspectors are right or left handed.

6. Four rows appear to be the optimum number of rows which should be presented for simultaneous inspection. (These results were determined for objects having a maximum "width" dimension of 2-1/2 inches. There is some reason to believe that this might not be correct for smaller objects. It is hoped that future work will determine whether it is the number of objects reviewed simultaneously or the width of the area which can be observed that determines this optimum).

7. Variations in the percent defective from 10% to 30% has negligible effect upon the inspection efficiency for a given set of inspection conditions.

8. For both direct and side approach the use of mirrors produces increased inspection efficiency in detecting end defects but reduces the efficiency in detecting peripheral defects. If the proportion of end defects is not high, the over-all effect of mirrors is reduced inspection efficiency.

9. When inspectors must inspect for more than one defect the over-all inspection efficiency is decreased. Increasing the number of defects from one to two decreases the efficiency about 3%.

10. When spheroidal objects are to be inspected using side approach it is desirable to cause them to roll laterally at least 1 inch in 5 inches of translation in order to assure that all of the surface can be seen. Some lateral movement probably is desirable when direct approach is used but it does not appear that it is a very important factor for this method of inspection.

11. The use of grading belts which will provide the conditions set forth in the foregoing conclusions can produce inspection labor savings up to 33 percent over typical procedures now commonly used in fruit and vegetable packing houses.

12. Workers have no difficulty in adapting themselves to equipment which provides the inspection conditions set forth in the preceding conclusions and seem to definitely prefer them over methods now commonly employed in the fruit and vegetable industries.

I will now let you see the motion picture which I believe you will find of considerable interest. Notice in this picture that in the laboratory tests that the fruit, namely lemons and oranges, were simulated by the use of wooden objects painted suitable colors. You will be interested in noting a similarity between the appearance and movement, obtained with these laboratory specimens, and the actual fruit in the packing house studies. If there are any of you who are interested in obtaining the complete results of these studies, if you will leave your name with me I will be glad to advise you when the complete report is released by the Department of Agriculture, and give instructions for obtaining a copy of this report.

* Film IE-4 "An Improved Method for Visual Inspection of Farm Products", Produced under direction of D. G. Malcolm and E. P. DeGarmo, University of California, 1952.

ACCURACY IN READING INSTRUMENT DIALS

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The design and arrangement of instrument dials must satisfy the major requirements that the dial can be read with accuracy and rapidity. These two factors -- accuracy and speed -- are present in varying degrees wherever dials are encountered, whether the dial is used on a steam boiler, a machine tool, or a stop watch; whether on an assembly line, in a power house, or in the cockpit of a jet airplane. Wherever dials are read or hand-wheels or controls are manipulated, two major requirements are accuracy and speed.

This need for rapid and accurate dial reading is especially imperative in the modern supersonic aircraft of today. In just one second's time these airplanes may travel almost one-quarter of a mile. If the aircraft is flying at night, the problem is intensified. The instrument dials must be illuminated at a light intensity bright enough to insure accurate dial reading. On the other hand, a low level of illumination in the cockpit is necessary to maintain the pilot's dark adaptation; that is, his ability to see objects outside the cockpit. Obviously, a compromise between these two divergent requirements must be determined.

This problem has been of particular concern to the Aero-Medical Laboratories of the United States Air Force's Air Material Command. It was in cooperation with that agency that this research was conducted. A specific purpose of the research was to determine a pilot's accuracy in reading his instrument dials as a function of the amount of time he was allowed to observe the dial and the brightness at which it was illuminated. Very briefly, the experiment involved projecting a dial image from a light-proof booth onto a screen observed in the dark.

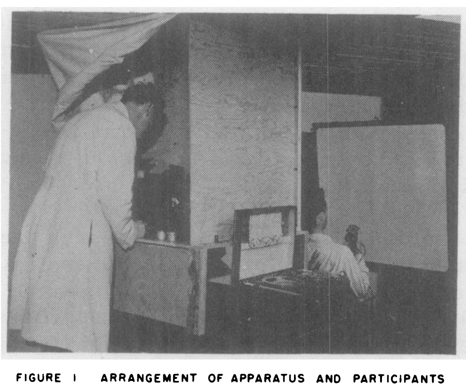

FIGURE 1 ARRANGEMENT OF APPARATUS AND PARTICIPANTS

The apparatus used included the booth, a projector equipped with a tachistoscopic shutter, a variable resistor to control the light intensity, a specially designed stimulus timer, a projection screen, a chair equipped with a head rest and a tape recorder. Figure 1 shows the projection booth with the projector and timer inside. Randomized settings of various dial readings were flashed onto the screen at randomized exposure speeds and for one of the three different levels of dial brightness. The head rest assured that the subject's eyes were kept a prescribed distance from the projected dial image. Because all of this was accomplished in total darkness, the observers' responses were recorded on a tape recorder and later were transposed to a data record sheet. There were thirty-six male subjects, all of whom were examined for their visual capacities and had 20/20 vision. Each subject was tested individually and was given a training session prior to the experimental tests.

Figure 2 shows the arrangement of the timer, projector, shutter, and Variac inside the projection booth. The randomized dial settings selected from a table of random numbers were filmed in advance on 35 mm. strip film. The strip film images were then projected on the screen during the experiment period. Because of the controlled order of presenting the film strips, dial brightness, and exposure times, none of the subjects had the same combination and order of these variables as any other observer. The order and design of the experiment were such that the effects of practice and fatigue were nullified.

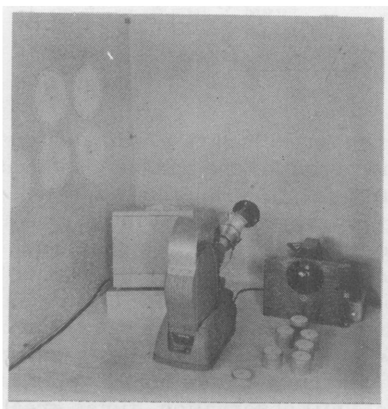

FIGURE 2. ARRANGEMENT OF STIMULUS TIMER, PROJECTOR, TACHISTOSCOPIC SHUTTER AND VOLTAGE CONTROL WITHIN THE PROJECTION BOOTH.

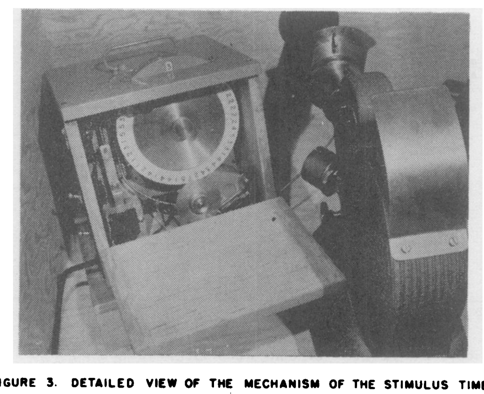

FIGURE 3. DETAILED VIEW OF THE MECHANISM OF THE STIMULUS TIMER

A close-up of the timing device constructed to trip the tachistoscopic shutter at prescribed intervals is presented in Figure 3. The numbers 1, 2, 3, 4, and 5 correspond to the five exposure speeds investigated, namely 1/20, 1/10, 15, 12, and 1 second. The three brightness levels studied were 2/100, 1/10 and 1 foot-lamberts.

A view of the instrument dial that was used is shown in Figure 4. The dial was 2. 8 inches in diameter and has been adopted as a standard for research of this nature by the Armed Forces - National Research Council Vision Committee. The results were presented in terms of the percent of dial readings in error and the absolute mean error of the readings. Any observation that varied from the actual by one unit or more was considered an error.

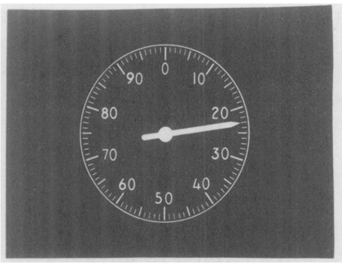

FIGURE 4. THE AIRCRAFT INSTRUMENT DIAL

THIS 2.8-INCH DIAMETER DIAL HAS THE FOLLOWING STANDARD DIMENSIONS AS RECOMMENDED BY THE ARMED FORCES-NRC VISION COMMITTEE FOR USE IN RESEARCH ON INSTRUMENTAL DISPLAYS SUITABLE FOR NIGHT LIGHTING AND 28-INCH VIEWING DISTANCE.

DIMENSION		MAJOR	INTER-MEDIATE	MINOR
GRADUATIONS	WIDTH	0.025 INCH	0.020 INCH	0.015 INCH
	LENGTH	7/32 INCH	5/32 INCH	3/32 INCH
NUMERALS	HEIGHT	3/16 INCH	—	—
	WIDTH	0.025 INCH	—	—

The graph shown in Figure 5 indicates the percent of dial readings in error for the various observation times and dial brightnesses. As would be expected, performance became poorer as the light intensity was decreased and as the observation time was shortened. However, one of the conditions this research brought to light was the high proportion of errors of one unit or more that prevailed even where the observer had 1/2 second to read the dial. Between 2/3 and 3/4 of such readings were erroneous. Furthermore, this high level of failures was almost constant until observation times greater than 1/2 second were allowed.

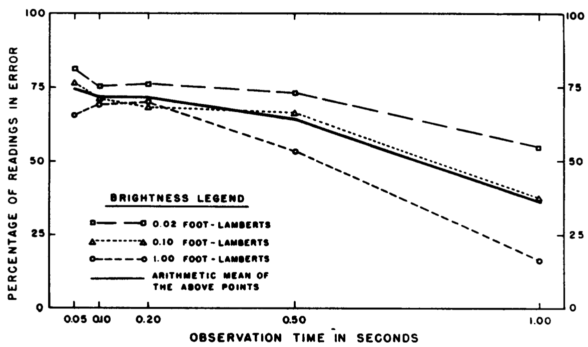

FIGURE 5. PERCENT OF DIAL READINGS IN ERROR AS A FUNCTION OF TIME FOR OBSERVATION AND DIAL BRIGHTNESS.

The graph shown in Figure 6 presents the data in terms of the absolute mean error sources for the range of dial brightnesses and observation times studied. An essentially linear relationship appears to exist between the size of the error and the exposure time.

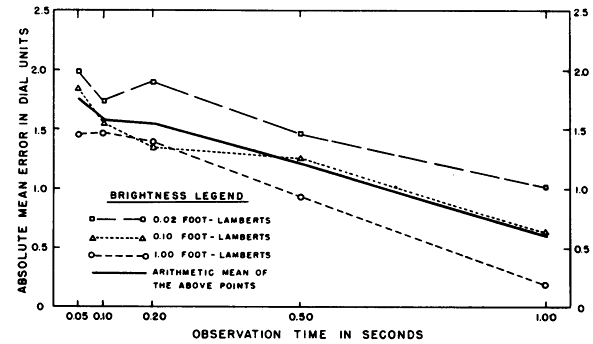

FIGURE 6. ABSOLUTE MEAN ERROR OF DIAL READINGS AS A FUNCTION OF TIME FOR OBSERVATION AND DIAL BRIGHTNESS.

On the average, readings were incorrect by 1 1/2 to 2 units at very short exposure times. At the highest brightness the average error was less than one unit when the observer had 1/2 second to read the dial. When given a full second for observation, the subjects averaged errors of less than 1/5 of a dial unit if the dial was illuminated at 1 foot-lambert.

Recent research by Fitts and his associates at Wright Field disclosed that pilots averaged over 100 dial observations a minute when flying routine aerial maneuvers. The average length of fixation cycle was slightly over 1/2 second per instrument. This value was included within the range of observation times allowed in the experiment herein described. In the light of the relationship shown in Figure 6, it would appear that if errors greater than one dial unit cannot be permitted, the dial must be illuminated at an intensity of 1. 00 foot-lambert. If an average of 1 1/2 units is permissible, the light intensity might be lessened to as low as 0. 02 foot-lamberts. As can be seen, this information will be useful to dial designers and cockpit layout engineers. It will also be of much use in future research in this field.

The research indicated the dependence of dial reading accuracy on observation time and dial brightness. To determine the statistical reliability of this dependence, an analysis of variance was made of the data. It was statistically shown that this dependence of accuracy on exposure time and dial brightness was highly significant. The analysis indicated that in less than one time in one hundred could the relationship indicated by these data have occurred merely by chance.

The results determined by this research are fundamental data and will be of use in future investigation of this nature. As far as is known, these data are the first statistically reliable measures of the proportions and magnitudes of dial reading errors for night flying conditions.

A STUDY OF THE ADDITIVE PROPERTIES OF MOTION ELEMENT TIMES[1]

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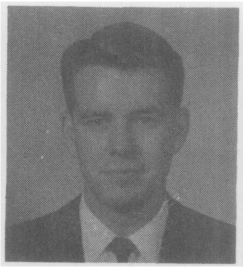

The introduction of pre-determined time standards has added greater significance to a basic but often neglected general criticism of work measurement methodology. The part-wise analysis and the subsequent synthesis of motion element times, is fundamental to standard data systems but critics of such methods claim that they are based upon an unsound atomistic concept of human behavior. Some industrial psychologists maintain that it is fallacious to consider any human behavior as being atomistic or compartmentalized by nature. Specifically, they question the assumption that each individual movement time of a complex task can be considered as a separate and independent unit. Proponents of this view state categorically that any task, however simple, must be considered to be an integrated whole whose characteristics are changed by the change of any of its parts.

The impact of this criticism has been rather underestimated by members of the industrial engineering profession. What it asserts in effect is, that the traditional engineering approach to work measurement (and to work methods as well) is contrary to the nature of human work.

Probably the most fundamental assumption involved in setting time standards by means of a system of standard motion times is that the motion times themselves are additive. It is clear, however, that the criticism of the atomistic approach attacks even this fundamental assumption.

The observable fact that a person skilled in a manual task blends his movements into a harmonious motion pattern is not in dispute and to this extent the industrial engineer is in agreement with the generalization about the wholistic nature of manual work. The essential question as regards work measurement, however, is whether the time values of motion elements are additive in the sense that they will combine to yield statistically reliable estimates of the whole task time.

The object of this study was to determine whether or not an additive set of motion elements in fact exist. To do this an experimental investigation was carried out in the University of California Industrial Engineering Laboratory. The remainder of this duscussion will be concerned with this experimental study, how it was conducted, how it resulted and what conclusions were drawn.

[1] Abstracted from a Masters Thesis performed under the direction of L. E. Davis.

Description of The Study

A manual task was developed which was capable of subdivision into smaller tasks composed of similar but fewer motion elements. Figure 1 illustrates the base task and the sub-tasks derived by successive elimination of motion elements. Each of the tasks consisted of a series of connective and manipulative motion elements. The subjects reached out to gain control of an alignment dial, rotated the dial 90° to align a pointer with a scale marking. Having aligned the first dial, the subject continued to the next, moving from dial to dial in a clockwise sequence until the number of dials included in the cycle were completed.

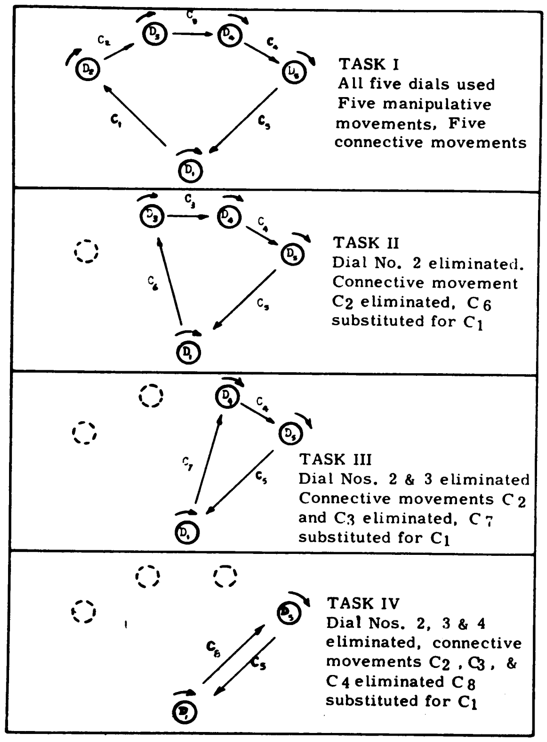

FIGURE 1. Diagram of Tasks

Task 2, 3 and 4 differed from Task 1 in that they contained fewer connective and manipulative movements commensurate with the removal of 1, 2 and 3 alignment dials from the cycle. The variable of alignment skill or precision of movement was introduced by using two sets of pointers. One set had an alignment tolerance of $\pm$ 1/8" and was designated as EASY. The other had an alignment tolerance of $\pm$ 1/16" and was designated as HARD.

Each of the twenty-four subjects (male, university students with preferred right-handedness, natural or corrected 20-20 vision) performed the four tasks under both alignment conditions. The subjects were divided into two groups of twelve each. One group performed the EASY alignment series first and the other performed the HARD alignment series first (in order to rule out, statistically, the effects of presentation). Within each group the order of task performance was arranged in balanced, incomplete latin squares.

Ten cycles of each task were measured per subject which resulted in 13,440 separate element times. (24 subjects, two alignments per task, four tasks of 10, 8, 6 and 4 elements respectively and 10 cycles per task.)

A pretest experiment was conducted to determine the number of practice cycles required for minimum performance time consistent with the alignment accuracy and the standard method. Thus the learning period was standardized. Subject motivation was high and as uniform as could be expected.

The motion elements were timed by means of a subject activiated, 10 pen, resistance type, polygraph (designed at the University of California) in conjunction with a thyrotion electronic relay circuit. The least count of the system was less than .0002 minutes with the smallest motion element time in the neighborhood of twelve times this amount. It was possible, therefore, to record minute variations in element times. Further, due to the method of timing (subject contact and dwell at the dial itself) very accurate end points were obtained.

An alignment "quality" circuit was built into the equipment so that by observing the chart records it was possible to determine whether or not the subject met the alignment precision requirements.

Figure II illustrates the experimental equipment.

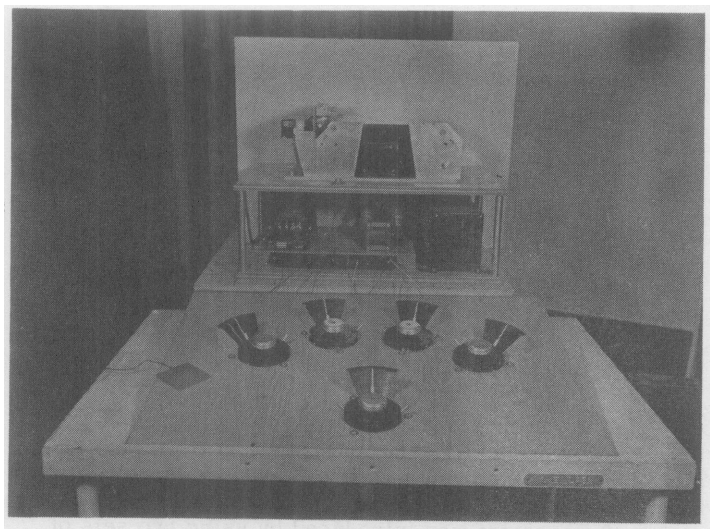

FIGURE 2

The five alignment dials are shown in the foreground and the timing apparatus in the background. The subject placed his left hand upon the contact pad shown at the left side of the layout completing the timing circuit.

Analysis of Data - Results

Several hypotheses were selected in this study for statistical analysis. The one most pertinate to this discussion reads as follows:

Task "A" contains all of the motion elements of Task "B" and in the same sequence. In addition, Task "A" contains elements not found in Task "B".

Hyp: There is no difference between the observed total time of Task "B" and an estimate of Task "B" made by subtracting the additional element times from the observed total time of Task "A". [2]

The reproducability of results is pragmatic evidence of reliability and is a criteria acceptable to the scientific method. The equivalence of task times based upon the whole task and an estimate of the same task which assumes additive motion elements was selected as the criteria of additivity in this study.

Each of the tasks 2, 3 and 4 were capable of estimation from task 1 by simply subtracting the appropriate element times from task 1. Estimated times for tasks 2, 3 and 4 were computed for each of the 24 subjects (for both EASY and HARD alignment) consequently the set of task times which resulted numbered 288, 144 estimated and 144 actual (24 subjects times 3 tasks capable of estimation via elimination of motion elements times 2 alignment requirements per task).

To test the Hypothesis given above, an analysis of variance with 4 variables of classification was performed for each of the three estimated tasks. The main variable tested was the significance of the observed differences between the actual task times and the estimated task times. The effect of Presentation, (HARD first vs. EASY first) Sequence (order of performing the tasks) and Alignment (time required for EASY vs. that required for HARD) were also tested in each analysis.

Table I summarizes the results of the analysis of variance.

TABLE I

Source of Variation	Significance			Probability Level
	Task 2	Task 3	Task 4	
Estimation	None	None	None	*
Presentation	None	None	None	.05
Sequence	None	None	None	.05
Alignment	High	High	High	.001

* The F ratio test statistic for the variable "estimation" was less than unity in each task indicating that the differences were completely explainable as chance variation.

[2] It is assumed that motion elements that exhibit additive properties, exhibit subtractive properties as well and vice versa.

Table II shows the average actual task time and the corresponding estimated task time. (Unit is 1/60 seconds. Each time an average of 24 subject performances).

TABLE II

	EASY Alignment Task			HARD Alignment Task		
	2	3	4	2	3	4
Actual	224.8	164.7	107.7	293.8	219.7	139.2
Estimated	220.8	163.0	105.5	297.0	220.4	144.0
Difference	4.0	1.7	2.2	-3.2	0.7	4.8
% of Actual	1.79	1.03	2.02	1.09	0.32	3.45

The estimated task times were not significantly different from the actual, therefore, the original hypothesis was not rejected. It is interesting to note that the presentation and sequence of performance did not affect the results. As was expected, there was a real difference in the times required to align under the two alignment conditions of EASY and HARD.

As will be noticed in Table II, the average absolute magnitude of the difference between the Actual and the Estimated Task times was below 3.5% in each case.

Conclusions:

Based upon the results of this study the following conclusions were reached concerning the additive (and/or subtractive) properties of motion elements:

1. It is possible to arrive at a set of motion elements whose mean times are additive as previously defined.

2. The elimination, and as a consequence the partwise treatment of motion elements, do not change the collective times of the remaining elements provided:

   a) The relative sequence of the elements remain unchanged.

   b) The elimination does not destroy the basic geometric movement pattern of the task.

   These restrictions to the conclusion apply because of the limitations of conditions in the task studied. Obviously more experimentation, using different kinds of tasks would be necessary to remove these restrictions if they actually exist.

3. It follows that the psychological hypothesis which asserts that the movement components of a manual task are uniquely dependent upon the whole task does not always hold true.

Summary:

The broad objective of this study was to determine whether it was possible to obtain an additive set of motion elements. It was concluded that additive elements do exist. The experimental approach was that of eliminating motion elements in order to measure the effect upon the elements which remained. Predictability of task times or the equivalence of actual and estimated task times was used as the criteria of summative properties.

Not all of the questions regarding the validity of the analysis-synthesis technique of work measurement were answered nor were they even explored. For example there is the complicated topic of substitution and/or combination of motion elements and the effect they may have upon the synthetic standard time. There is certainly a great deal of fundamental research needed before a general theory of work measurement can be established.

The art and science of work measurement is comparatively young. There is not now and there may never be complete agreement as to its scientific validity. The central theme of this discussion suggests however, that the synthesis of time standards using elemental motion times is conceptually sound as regards the basic assumption of additivity.

A STATISTICAL ANALYSIS OF VISUAL INSPECTION METHODS

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The purpose of this study was to investigate the performance of operaators engaged in the visual inspections of spheroids under varying work methods and workplace design.

The spheroids used in the tests were 2 1/2 inches in diameter and were orange colored. The spheroids which were considered defective had **a 1/8 inch diameter** black spot on them. The spheroids were presented to the operators on a conveyer table which was designed so as to provide various combinations of lineal speed and rotational speed.

The task of each operator was to remove the defective spheroids from the table, as the spheroids were conveyed along the table, and to place them in a chute in front of him. The statistic used to determine the efficiency of the inspection was the "Final Percent Defective" of the lot used for the test, or the ratio of the defective spheroids present in the lot after inspection to the lot size after inspection, expressed as a percentage. The lot size before inspection was 1,000 in all tests.

Several variables appeared to be important in determining the efficiency of the inspection. These were:

1. Inspection Speed: The rate at which the spheroids were conveyed linearly along the table.

2. Rotational Speed: The rate at which the spheroids were rotated during the inspection.

3. Percent Defective: The percent of the lot which was defective before inspection.

4. Direction of Approach: Two workplace designs were possible, allowing the spheroids to be presented to the operator from his right and passing to his left, or directly toward the operator with the flow terminating in front of him.

5. Number of Rows: The number of parallel rows of the spheroids across the width of the conveyer table.

[1] Abstracted from M. S. Thesis Research performed under the direction of D. G. Malcolm.

In addition to the above variables, another was introduced in order to study a different feature of workplace design. This was Concurrent Re-inspection, where again two workplace designs were possible. The first allowed the inspector a single inspection of the spheroids before the efficiency of the inspection was determined. The second design allowed a second inspection by returning the spheroids, after the initial inspection, to the conveyer table in rows parallel to the rows of the spheroids being inspected for the first time. For example, in two-row inspection, without concurrent reinspection, two parallel rows of spheroids would be conveyed along the table. In two-row inspection, with concurrent reinspection, four parallel rows of spheroids would be on the table, two rows having already been inspected and two rows being inspected for the first time.

In order to adequately study the number of variables under consideration, without excessive testing, an experimental design was established using a method of statistical testing and analysis which is relatively new to the engineering field. This method, sometimes referred to as "Magic Squares" or "Orthogonal Squares", utilizes the incomplete block design, wherein each level of each variable is tested once with each level of the other variables according to a prescribed pattern, rather than with all possible combinations of the other variables. The value of such a design can readily be appreciated when it is realized that 192 tests were made using this design, while 1,536 tests would have been necessary for comparable evaluation of the variables without the use of the incomplete block.

Several levels of testing were possible for the Inspection Speed, the Rotational Speed and the Percent Defective. Four levels were chosen for each of these variables so that the midpoint appeared to be close to the point of most interest, with a maximum range on either side of the midpoint. The Inspection Speed ranged from 3 to 4 1/2 minutes for the inspection of 1,000 spheroids. The Rotational Speed ranged from 1 1/2 to 3 revolutions per foot of lineal travel. The Percent Defective ranged from 10% to 40%.

The other variables, because of their nature or because of machine limitations, were tested at two levels. The Direction of Approach varied between Side, with the spheroids approaching the inspector from his right, and Direct, with the spheroids approaching the inspector from the front. The Number of Rows was either two or three. Concurrent Reinspection was present in half of the tests.

The block pattern was then prepared, using a four by four square. The levels of the variables were assigned to the block so that each level of each variable appeared once with each level of the other variables. In the case of those variables having only two levels each level appeared twice with each level of the other variables, in order to complete the 16 grids of the block.

The incomplete block design will not reveal interaction between variables if only one test block is used. As it appeared that interaction might be present between the Inspection Speed and the Rotational Speed it was necessary that four separate blocks be used, each composed of 16 tests, with the levels assigned so that all possible combinations of these two variables appeared in the complete design.

Twelve operators were tested, with each operator performing all the tests in one of the four test blocks. The operators were assigned to the test blocks on the basis of their performance in training tests, so that the range of the operators' proficiency was similar in each block.

The analysis of the data derived from the testing was composed of two separate parts. The first part was the determination of the significance of the connection between the inspection efficiency and each of the variables, and the experimental error of the tests. The second step was to determine the form of the connection between the variables and the inspection efficiency, where such a connection was found to be significant.

The analysis of variance was used to determine whether or not a significant connection existed between the inspection efficiency and the variables. When the analysis of variance is used, however, a basic requirement is that the variance of the data being analyzed must be uniform, or nearly so, over the range of the data so that the mean squares being studied are independent. As the results derived from the inspections were in the form of percentages the variance of the data tended to follow a binomial distribution, so that it was necessary to adjust the data before the analysis of variance could be used. The correction used converted the percentages into angles where

$$\text{Angle} = \text{Arc sin} \sqrt{\%}$$

The corrected data was then used throughout the analysis of variance.

The analysis of variance determined that all the variables studied were significantly related to the efficiency of the inspection. The expected interaction between the Inspection Speed and the Rotational Speed, however, was found to be insignificant. The individual standard deviation or experimental error of the individual reading, was 0.39%. This would indicate that all the important variables were probably included in the study.

Those variables which were tested at two levels showed the following relationships to the inspection efficiency:

1. Direction of Approach: Direct approach was more efficient than Side approach, with the mean values for the final percent defective being 5.44% and 7.31% respectively.

2. Number of Rows: Three-row inspection, with a mean value of 4.70% defective in the inspected lot, was better than two-row inspection, which resulted in a final percent defective of 8.05%.

3. Concurrent Reinspection: The mean value for the final percent defective was 4.78% when concurrent reinspection was present in the tests and 7.97% when it was not present, indicating that the performance of the operators was benefitted by its use.

The values indicated above, being mean values, apply only at the average level of the other variables.

A more complete analysis was possible for those variables which were tested at four levels. The method of Least Squares was used to establish the following estimating equations, with each equation applying only where the average level of the other variables is used:

1. Inspection Speed: A linear connection was found, of the form $P = 17.55 - 2.98(IS)$ where P is the final percent defective and IS is the inspection speed in minutes per 1,000 spheroids.

2. Rotational Speed: A quadratic connection was found, of the form $P = -14.07 + 17.97(RS) - 3.72\,(RS)^2$ where RS is the rotational speed in revolutions per foot of lineal travel.

3. Percent Defective: A linear relationship was found, of the form $P = -1.37 + 31.0(DEF)$ where DEF is the proportion defective in the lot before inspection.

The final determination of the form of the connection of the variables to the inspection efficiency may be carried one step further because of the orthogonal properties of the original test design. The estimating equations shown above may be combined into a single estimating equation, with the two-level variables specified at given levels. Several combinations of these two-level variables are possible, but the two that are probably of most interest are shown below:

1. a. Conditions: Three-row inspection, direct approach, with concurrent reinspection.

   b. Estimating Equation:

   $$P = -13.25 + -31.0(DEF) - 2.98(IS) + 17.97\,(RS) - 3.72\,(RS)^2$$

2. a. Conditions: Three-row inspection, direct approach, without concurrent reinspection.

   b. Estimating Equation:

   $$P = -12.18 + 31.0(DEF) - 2.98(IS) + 17.97\,(RS) - 3.72(RS)^2$$

This study has by no means exhausted the research of the methods of performing visual inspection, but it is hoped that it has pointed the way to further research on this subject. The use of the incomplete block design for the testing performed for this study has proved to be of great value. The design should prove to be of equal value in further applications in this or many other fields.

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AN ANALYTICAL AND GRAPHICAL SOLUTION FOR SOME PROBLEMS OF LINE BALANCE

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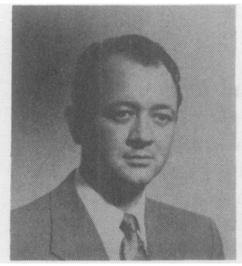

During and since World War II, the importance of line production has been mounting, and it is probable that as standardization continues and volume increases line production will become more common. One of the most important problems in the engineering of a production line is balancing the line to achieve the maximum utilization of labor and machines, and minimum in-process inventory.

Line balance in the ideal case results in equal output per unit of time from each of the operations in the sequence. There are several means for trying to equalize the output, among them being methods study, combining and subdividing operations, and operator selection. Of course methods study includes a study of the machine, its speeds and feeds, a study of the operators' motions, material handling, tooling, and a study of the product design as well. Combining and subdividing operations is particularly applicable in the balance of assembly operations. If no actual change can be effected in standard times of the elements or in the relation of the elements a degree of balance may be obtained by selecting fast operators for the slow operations and vice versa. It is not the purpose of this paper to discuss the above thoughts exhaustively. The reader is referred to R. Muther's[1] treatise on Production Line Technique for a fuller discussion. The particular problem to be considered here is one which often follows the effort to achieve the best balance possible (i. e., equalization of output).

Assume a fabrication line in which the balancing process has already taken place. The required output of the line is 300 pieces per day. Selecting two operations in the sequence with their standard outputs given the machine-hour capacities can be calculated.

	Pieces/Hours	Machine-hours/8 Hour Day
Operation #1	25	12.0
Operation #2	60	5.0

It is evident that for an eight hour day, Operation #1 will require the use of two machines for part of the day. The two machines could be employed in a number of ways. The machine-hours could be divided between the two machines or one machine could be used for the full eight hours and the second employed for the balance of time required. The latter case is probably more common because of greater ease in utilizing manpower fully.

In order to explore the second case more carefully let us further assume that all machines start at the beginning of the work day. Figure IA gives a graphical picture of the relations of the operating times. The rise and fall of the bank of material between the two operations can be analyzed by means of the simple relation:[2]

$$B = (C_1 - C_2)T$$

Where B = bank size, pieces,
C_1 = capacity of Operation #1, pieces per hour,
C_2 = capacity of Operation #2, pieces per hour,
T = time period over which C_1 and C_2 operate, hours.

When B is positive the bank is being built up; when B is negative the bank is being drawn down.

By inspecting Figure I it is seen that there are three different conditions of flow.

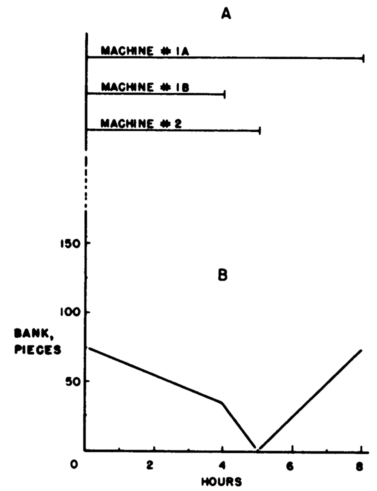

FIGURE I
BANK LEVELS BETWEEN OPERATIONS #1 AND #2, ALL MACHINES STARTING AT THE BEGINNING OF THE WORK DAY

The first is in effect from the beginning of the day until Machine #IB is shut down. During this period all three machines are running. The second condition of flow is in effect from the time #IB shuts down until #2 shuts down. During this period Machines #IA and #2 are running. The third condition is in effect from the time #2 shuts down until the end of the day and only #IA is operating during this period. By applying the formula, $B = (C_1 - C_2)T$ to the three conditions, the curve describing the bank level throughout the day can be determined quickly.

Condition #1, $B = (50 - 60)4 = -40$
Condition #2, $B = (25 - 60)1 = -35$
Condition #3, $B = (25 - 0)3 = 75$

Figure IB shows the resulting curve. At the beginning of the work day, a bank of at least 75 pieces must be avail-

1. Muther, R., Production Line Technique, McGraw-Hill Book Company, Inc., New York, 1944, pp. 112-132.

2. Op. cit., Muther, R., p. 110

able for Operation #2 to draw on. At the end of 5 hours production the bank would be drawn down to zero, at which point Operation #2 is shut down. For the balance of the day (3 hours) Machine #1A continues to produce 25 pieces per hour and builds the bank back up to 75 pieces at the end of the eight hour day. The resulting information is important because it shows that the line could not operate smoothly throughout the day unless the work day was begun with a bank of at least 75 pieces between Operation #1 and #2. This information also indicates the amount of storage space required between the operations. If a conveyor was to be used for transportation and storage between the two operations, the minimum length of conveyor required would be controlled by the maximum bank that occurs during the work day.

Other alternatives for the starting time of Machine #1B and #2 are of course available, but they are not all equally good. Any alternative which increases the maximum bank will increase the average in-process inventory and all costs that are affected by the level of the in-process inventory. To show the range of maximum bank levels that can occur with alternate starting times, assume the starting times shown in Figure IIA.

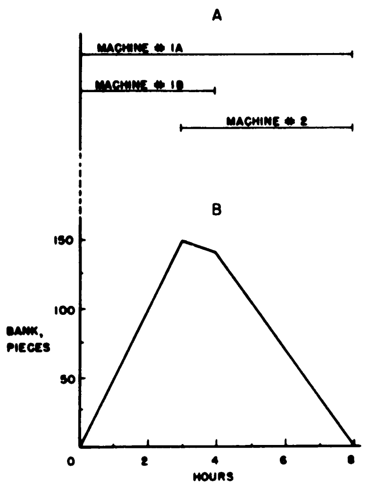

FIGURE II
BANK LEVELS BETWEEN OPERATIONS #1 AND #2. EFFECT OF DELAYING THE STARTING TIME OF MACHINE #2 FOR 3 HOURS.

Again there are three conditions of flow and the resulting bank calculations are as follows:

Condition #1, B = (50 - 0)3 = 150
Condition #2, B = (50 - 60)1 = -10
Condition #3, B = (25 - 60)4 = -140

The resulting bank curve (Figure IIB) shows that the maximum bank is 150 pieces and that it occurs after 3 hours of operation.

A Range of Starting Times:

A closer examination with the aid of graphics will show that there is a range of time in which Machine #1B can be started which will not affect the maximum bank of 75. Assume the general conditions of Figure I and determine the starting time for machine #1B.

At the beginning of the work day we have two alternative conditions, either that Machine #1B starts then or at some later time. If Machine 1B starts at the beginning of the day, we can draw a straight line with slope -10 pieces per hour (line AB', Figure IIIB) to indicate that the bank is being drawn down at this rate. The alternate condition is where Machine #1B starts at some later time. In this case we can draw a straight line with slope -35 (line AC', Figure IIIB) to indicate that the bank is being drawn down at this rate.

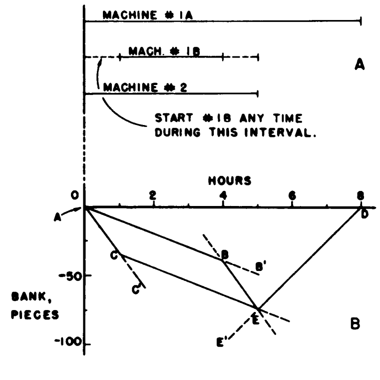

FIGURE III
GRAPHICAL METHOD FOR DETERMINING OPTIMUM MACHINE OPERATING TIMES. MACHINE #2 STARTS AT THE BEGINNING OF THE WORK DAY.

If we assume that Machine #1B starts at the beginning of the day, then a line of slope -35 can be drawn through point E.

At the end of the day only Machine #1A is operating so a line DE' can be drawn with slope +25 to show that the bank is being built up at the rate of 25 pieces per hour. This condition is in effect for the last 3 hours of the day. It can be seen by inspection of the graph that if Machine #1B operates during the last 3 hours of the day that the maximum bank of 75 pieces would be increased. This would be contrary to the stated objectives and so with the case under consideration, Machine #1B cannot be running during the last three hours of the working day. Then when can it be operating? From the graph it can be seen that the latest time which machine #1B can be started is one hour after the beginning of the work day. Figure IIIB also shows that it could be started anytime between the beginning of the work day and the end of the first hour of operation. Any starting time for Machine #1B during this interval will not affect the magnitude of the maximum bank. Any line parallel and between lines AB' and C'E represents the effect of the different satisfactory starting times of Machine #1B.

The other typical case for solution is where Machine #2 works the last 5 hours of the day instead of the first 5 hours. By similar reasoning it results in a graph (Figure IV) which indicates that Machine #1B can be started any time between the 4th and the 5th hour of operation. The maximum bank is still 75 pieces, but it occurs at the end of the 3rd hour of operation instead of at the beginning and the end of the eight hour period.

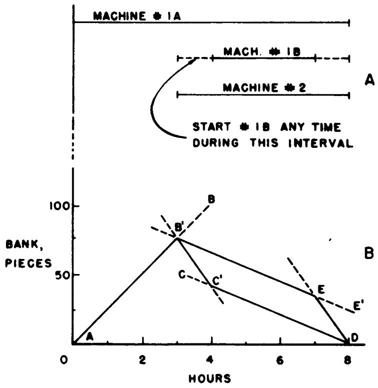

FIGURE IV

GRAPHICAL METHOD FOR DETERMINING OPTIMUM MACHINE OPERATING TIMES. MACHINE #2 STARTS ON THE THIRD HOUR OF OPERATION.

Conclusions:

The above analysis of banks in a production line is of importance when an operation in the sequence requires more than one machine to produce the requirements of the line. It is not useful in the simple case when only one machine is required at each operation. When more than one machine is required the proper analysis shows that there is an optimum time to start the second machine, usually a range of time over which the machine can be operated without affecting the optimum inventory conditions between the operations.

Of course for a complete and proper analysis of a production line, these calculations would have to be made to determine the banking conditions between all operations in the sequence, in order to allocate the proper amount of in-process storage space. In cases where a conveyor is to be used for internal transportation and in-process storage, calculations would yield the required length of conveyor between operations.

Other factors may serve to complicate the problem, but they do not basically change it. Where plant efficiency is known it serves to reduce the total productive machine time. This should be reflected in the design capacity of the line. The ebb and flow of the banks between operations would then be based upon the resulting machine combinations.

The output standards used in calculations of this nature should reflect actual output conditions. Production standards are often quoted at other than expected levels, for reasons relating to a particular incentive plan. It should be noted however that when they are used to determine productive and storage capacities that expected values should be used.

RESEARCH DEVELOPMENTS OF QUANTITATIVE METHODS IN PRODUCTION

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I. Introduction

The subject on which I am to speak today is both an opportunity and an impossible task. I consider it an opportunity, because I am much devoted to development of quantitative methods, and because I believe they will play an important role in industrial engineering of the very near future. It is an impossible task because there have been so many developments, all uncoordinated from the point of view of the Industrial Manager, that tying them into a convenient package is virtually impossible in such a short talk. It is possible therefore only to mention what I believe to be the more important areas without probing deeply into the core of these developments. Also, in view of my particular interest in the Industrial Logistics Research Project, I will mention its work and objectives.

In covering the subject here, I will adhere the following outline:

a. A brief introduction to what I believe are the important advantages to be gained from the systematic introduction of quantitative or "scientific" method in Industrial Engineering and Management.
b. A brief survey of the work being done by various groups which can now or will contribute in the future to Industrial Engineering and Management Theory and Practice.
c. A brief survey of the work of the Industrial Logistics Research Project.
d. The need for the Industrial Engineer and Manager, both in industry and in research to become familiar with this work in order that these diverse fields may be "tied" together into an integrated discipline, such as has been done already in fluid mechanics, thermodynamics, etc.

For the convenience of those who may find an interest in these notions, a representative bibliography is included at the end of the paper.

II. Opportunities for the "Scientific" Method:

Perhaps in no other field of human endeavor is there such a gap between proven scientific theory on the one hand and applied practice on the other, as there is in the field of Industrial Engineering and Management. We shall not attempt here to fully explore the reasons for this; but at least a few come to mind as rather obvious. First, as Taylor mentioned some fifty years ago, "good" management is neither a necessary nor a sufficient condition for profitable operation of an industrial enterprise. It is not sufficient because profitable management is heavily dependent upon "entrepreneurship" - or happening to take the "right" risk and having that risk "pay-off" by virtue of the innumerable factors external to the control of the manager.[2] It is not a necessary condition, because not enough firms really have "good" management, that is, it is not necessary for effective competition. Hence, the "pressure" to improve management methods has not been as insistent as in the sciences, where for example, there is virtually no "pay-off" for any research which is not "the best".

If "good" management is neither a necessary nor sufficient condition for profitable industrial operation what then, is the case for improving management of industrial enterprises? It is simply this: the more efficient is the management of an enterprise, the greater the profit or the smaller the loss from risk-taking. That is, entrepreneurship is something like quality-control; we can never eliminate completely variability in either's "chance cause" system. But, as in quality-control we can use powerful statistical methods for controlling and, <u>in the aggregate</u>, rationalizing the enterprise or the production operation, such that, <u>on the average</u> the pay-offs from a series of risks or production operations will be greater than if these methods were not used.

Hence, in this talk today, I can no more say than that if you use the methods we are to discuss, you will be assured, as in quality-control, that the average performance or profit will be higher; but in any particular venture, risk-taking, or production operation, you cannot be insured against the chance-cause system generating some "rejects" or net losses, instead of profits. About all you can do is to improve your quality or profit control techniques and be assured that you will be "right" more often. It is on this basis, then, that I wish to discuss the subject of this talk.

I take the time to mention the foregoing because often you will find a person who will argue against these methods because "I have made a good profit without them". But, in not an infrequent number of cases, it is possible to probe further and find that, although he did make a "good" profit, he had been in an expanding market and actually had lost relative ground; or he has had a "patent" monopoly and had earned less than he might have, if he had good management; or other. It is in this "extra" dividend from more scientific methods of management that we are interested here.

Now, let us explore the methods and advantages of using quantitative techniques. The most important argument for these is "<u>Things are not always as they seem</u>". It is surprising how small the plant may be, and still we find that the intuitive or judgment picture is misleading. This is due to the intricacy and complexity of the problem confronting industrial management and from the fact that the exact relations between the factors in these problems are not always obvious. Under these conditions, we need to develop an aid for our reasoning and decision-making processes, such that we are guided reliably through the

1. Prepared while the writer was under contract to the Logistics Branch, Office of Naval Research and at the Industrial Logistics Research Project, University of California, Los Angeles.

2. Alchian, A.A., "Uncertainty, Evolution, and Economic Theory". Journal of Political Economy, June, 1950.

the "maze". To find our guide map, in quantitative methods, we use necessarily mathematical methods. But, this is a large advantage in our "thinking" process. For example, to quote one experienced mathematician, Dadourian reports, "When a chain of reasoning is carried out in the language of mathematics, the reasoning process is surer and swifter. When a law of nature is expressed in the mathematical language, it not only becomes more precise, but its hidden implications come to the surface. An illustration of this characteristic of mathematics is given by Clerk Maxwell's discovery which led to the development of radio, radar, and television. When Maxwell expressed the experimental laws of electromagnetism in the form of the four equations named after him, he discovered the fact that electro-magnetic disturbances travel with the velocity of light. This prompted Hertz, who experimentally proved Maxwell's discovery to exclaim 'Mathematical equations are wiser than we'." This being the case, how can we tap this additional source of wisdom for the solution of our management problems.

Thus far, isolated research and application has led to proof of this gain in wisdom in a host of management problems, including production scheduling, blending or mixing ingredients, scheduling transportation, marketing and distribution, financial and investment policies, work measurement, organization and procedures, etc. Hence, the range of application is seen to be large; the improvements in profit or productivity in the situations with which I am familiar also are large, ranging up to 44 percent over those achieved using conventional intuitive and judgment methods.

III. Survey of Relevant Work:

I shall avoid being so ambitious as to "prophesize" what current work is or will be relevent to the improvements or theory and methods in industrial engineering and management. This is for two reasons, equally important here: First, if I took time to keep abreast of all potentially useful work, I should have no time left over for research and teaching. Second, if I did know all of these research projects, I should need omnipotent wisdom to be able to predict which of them eventually would be useful. Hence, what I shall mention here is a limited (to the extent of my knowledge) and biased (according to what I think is important) sample of research studies which give promise of useful application in Industrial Engineering and Management, either now or at some time in the future.

Further, I cannot, by the sheer size of the task, integrate these diverse developments into an integrated and logical pattern. This is, in itself a formidable challenge to the researchers and practitioners in industrial engineering and management. I believe that, if we are to have such an integrated body of knowledge, we must develop it, since we cannot expect the mathematician, electronics engineer, or other technical specialist who makes some contribution in one part of our field, to fit the pieces together into a mosaic of theory and method for us. Hence, we need to become aware of these developments, scan them for useful application, and to integrate them into a body of knowledge which will represent the theory and practice of "management".

In order to provide a "framework" within which you may orient the studies to be mentioned, I will give first a brief sketch of one method of viewing the operation of an industrial enterprise. I hope that the way these particular studies "fit" into this framework will be obvious to you. This framework is not either novel or new, simply convenient here.

An entrepreneus decides to initiate an enterprise. He provides the risk capital to produce the commodities he is to sell. He or a deputy "manages" the enterprise. He must determine what he is to produce, how many to produce, what he must purchase, how he is to produce, the time schedule for his production, and similar decisions. These fall into a broad classification of "planning". In any but a one enterprise, these tasks must be delegated in some logical manner in relation to the functions which must be performed. Since all delegates (executives) are serving a common cooperative purpose, there must be communication of information among the delegates according to the requirements of each function in relation to the others. There must be, therefore, an effective communication network. In addition, he must provide for actual execution of the plans by the "production" department. In order to assure that production is according to plan, there must be a method of control and error correction (all processes, human and machine, being characterized by probability distribution functions, inevitably introduce some pertubations). Finally, there must be a "replanning" system to act on the errors and aberrations and assure that plans remain consistent with the objectives and with the state of information on the enterprise and its environment at any instant in time.

Now, let us review briefly various of the studies that will contribute to the "managerial" process.

1. Organization Theory: Properly viewed, the function of an organization is to process data and to make decisions based on the inferences to be drawn from the information made available by the process transformations on the data. Important contributions to the development of a theory based on quantitative concepts have been made by Morgenstern (Princeton) in his studies and have led to his "Prelegomena to a Theory of Organization". It sets forth qualitatively the elements to be considered in a subsequent work treating the subject quantitatively. It is unique in many respects and promised to lead to useful theories and methods. Marschak (University of Chicago) has gone one step further in reporting his studies in "Basic Problems in the Economic Theory of Teams" and has evolved a mathematical structure on which further experimental development can translate theory into practices.

A forthcoming book by Von Neumann (Princeton) will give his treatment of the "Theory and Organization of Complicated Automata". It can be expected to yield further developments to organization theory as fundamental as those in his book (with Morgenstern) "Theory of Games and Economic Behavior". Simon (Carnegie Institute of Technology) has taken a fundamental step in his studies and has drawn clearly the analogy of an organization to a serve. This has been described earlier by Wiener (Cybernetics: Communication and Control in the Human and Machine), but was carried past the theoretical stage by Simon, who now is continuing the studies at the experimental level. (The Theory of Servo-mechanisms in Relation to Production Control). Tompkins (INA-UCLA) has studied the computational problem prerequisite to the use of Marschak's organizational methods with an eventual goal of handling many such problems electronically. (Notes on Computational Aspects of a Combinatorial Problem in Organization Theory formulated by J. Marschak, I and II).

2. Communication and Information Theory: Fisher (The Logic of Inductive Inference) initiated much interest in information theory from a statistical point of view. Clearly, statistics is concerned with the extraction of information

from data by various mathematical operations. This finds its place in management by establishing criteria on the amount of information, its reliability, etc., available in the data and hence available to the manager for his decision making. Shannon and Weaver have taken a different approach (Mathematical Theory of Communication) which, while interesting, is not in the form which can be applied to information problems as ordinarily presented in management; an important step to adapt to managerial situations was initiated by Bavelas (Massachusetts Institute of Technology) in studying experimentally the communication process of small task-oriented groups, that is, (groups engaged in cooperative problem-solving and constrained to solve these problems by inter-personal communication). Many of Bavelas conclusions on the effectiveness of group problem solving under different communications restrictions were substantiated by empirical observations in a large chain department store.

Wiener's work can be mentioned again as providing a framework on which to hang the "error correction" function in communication and control. It brings into potential use in the study of organizations much advanced work in servo and network theory. It is clear, therefore, the organization, communication theory and information theory are intimately intertwined in any real application. Inasmuch as the Industrial Engineer has traditionally been one of the persons more frequently responsible for developing organizational structure, management systems, forms and procedures, etc., it is to be expected that he will have to assimilate these advances as they are developed if he is to continue to retain his position in this field. It is interesting to note, that virtually all of the above mentioned are mathematicians, mathematical economists, or engineers with unusually advanced training in mathematics. It appears that we shall have to bring ourselves up closer to their mathematical level if we are to obtain the full advantage of their work.

3. Work Measurement: The planning and prediction functions are predicted in the assumption that we can predict the outcome of controlled processes. But, since all processes (human and machine) are properly characterized by probability distribution functions, it is as important to have information on the statistical parameters of these functions as on the single value (mean, median, or mode) that is now usually taken to represent the process. That is, it is necessary to know and use certain of the statistical properties of work standards, etc., if the planning and prediction functions are to be properly carried out. Koopmans has made an important contribution in relation to the external facts (Statistical Inference in Dynamic Economic Models), although many others also have studied business cycles from a statistical point of view. Davidson (Functions and bases of Time Study) and Abruzzi (Work Measurement) have taken important steps in the use of more adequate statistical methods in measurement of the human portion of work processes. Little has been done in relation to measurement of the statistical properties to the machine component. Surprisingly, a study by Balaseyus indicates there is great need for such research.

The proper recognition of the probability character of all processes in the industrial environment is important also to organization theory because it is the measure of variability and reliability that determine the frequency of perturbation from plan and hence the need for the members of the organization to communicate information on any perturbation in order to correct the resulting "error" (in the servo sense).

It is interesting to note again that the persons mentioned here are persons with a strong orientation toward the use of mathematics in their work. It is also interesting to note that of the criticisms made of predetermined elemental motion-time systems and other similar time study work, the inadequacy of the statistical analyses appears most frequently. Of further interest, is that those whose work is so criticized, have little rebuttal without carrying out their work again with more adequately designed experiments and by analyzing the results with adequate statistical methods.

4. Statistical Decision Functions: Closely related to the statistical character of the industrial environment and to the need to make decisions based always on incomplete information is the statistical decision theory developed first by Wald (deceased) continued by Wolfowitz (Cornell), and being studied experimentally by Bechhofer (Cornell). One particularly well developed application of this theory is the sequential sampling procedures used in quality control, etc. However, the concept applies to virtually all other types of managerial decisions. The technique simply has not been recognized as yet as a tool for solution of broader management problems. Wolfowitz and others have made important theoretical strides in this direction in relation to inventory control. Again, the pioneers have been mathematicians.

5. Linear Programming: The objective of any enterprise (profit seeking, eleomosynary, governmental, or other) is to maximize some objective function consistent with constraints and conditions imposed in the phenomenal world. The objective function is measured in terms of profit, cost, service rendered, or some combination thereof. Linear Programming is a mathematical method of seeking some schedule or program of activities which optimizes this objective function. In general, it does so by a level of analysis essentially equivalent to what we familiarly call "shop loading". It is equally applicable to many other problems such as blending and mixing, transportation, sizing, etc. For example just last week I had an opportunity to discuss with the manager of an agricultural association's packing house how this method could be applied to his mixing and transportation problems. Linear Programming has been applied on a limited, but successful, basis by Charnes and Cooper (Carnegie Institute of Technology) to manufacturing refining and Koopmans (University of Chicago) to transportation. Dorfman (University of California, Berkeley) has bridged much of the gap between economic theory and business management in his "Linear Programming and the Theory of the Firm".

This technique finds its origin in the mathematical economics seminars in Vienna and its earliest steps toward application were by Dantzig, a mathematician. It was first developed for programming Air Force activities by the SCOOP Group (Scientific Computation of Optimum Operating Programs) in the Department of the Controller, USAF.

Again, Dantzig was a mathematician, and the others mentioned were similarly trained or oriented.

6. Electronic Data Processing: One of the wonders of the modern scientific world which is making many of the preceding developments possible is the electronic data processing machines and computers being developed by a large number of governmental, University, and commercial groups. One of the foremost is located on this campus, the Institute for Numerical Analysis. The potentialities of these machines are now forcing a revolution in thinking in regard to the managerial process. Already they may take over and perform many decisions and functions more efficiently than humans. But, for all their speed, they are no more than extremely fast, but equally stupid clerks -

in the sense that they will do extremely rapidly what you spell out in exact detail for them - but no more than you have specified. Hence, in order to use them, we must know "exactly" just what we are really trying to do in the managerial process. This doesn't mean definitions such as, for example, the one given by Betchel, et al, that "Scheduling is fitting operations into a logical timetable"; the machine just wouldn't know what is logical - any more than you or I really know. But, if you state that it is optimizing some linear form constrained by specified side restrictions, if you make explicit the functions and constraints, and if you program its computations, it can generate an optimal schedule for you.

I think we can expect inevitably to find ourselves married in the office to these high speed clerks, and we ought to begin finding out more about them very soon. At least the New Yorker's article that we should make the Univac our President, and then elect the man to feed information into it at least drives home the fact that we may expect to see more machines of this type in or associated with executive functions.

Interestingly, the first computer incorporating any modern elements at all was the "difference engine" designed by Babbage (1832), a mathematician who in his spare time scooped F. W. Taylor by fifty years as the real father of scientific management.

7. Operations Research: For all of the important contributions published under its name, I am not sure where to classify operations research, or more correctly, I believe, operations analysis. For all the definitions I have read (almost every article contains at least one) it is not exactly clear where it would differ from conventional industrial engineering, if more industrial engineers were to use better mathematics, statistics, and probability theory as a basis for more of their work and call more frequently on other supporting disciplines where necessary. The most frequently cited definition (by Morse and Kimball) defines it as "providing quantitative bases for executive decisions". Well, so do all of the foregoing mentioned subjects, as well as industrial engineering provide a quantitative basis. Is operations research all of these? I think it isn't; it is just that brand of industrial engineering which was developed by those scientists who were called upon to help solve operating problems. The only addition was that they had adequate training in mathematics, etc., to handle the problems on a quantitative basis and brought in specialists where needed. Further, I think OR will fuse with industrial engineering as these scientists are able to go back to their laboratories and the industrial engineering and management education and training come up to the level of physics, chemistry, etc., so they can take over. I doubt that industrial engineering plus mathematics and the scientific method equals operations research. They basically are just two names for the same thing. If Industrial Engineers should have more mathematics and a broader basis in science for solving their industrial problems, it is the responsibility of the universities adequately to improve the mathematics in the Industrial Engineering curriculum. OR has given us a good start; it is now up to us as Industrial Engineers to pick up the ball and carry these methods forward in industry.

8. Human Relations: I have emphasized the non-human elements of managerial organization and decision making. I do not undervalue the human relations problems. In the use of quantitative methods, however, we are largely confined to use of numbers; I have not yet seen much evidence that we have been able to quantitize "human behavior", although some work is being done in this direction e.g., Kurt Lewin (Topological Psychology), the Michigan Social Science Research Center, etc. For the purposes discussed here, it is minimally satisfactory to assume that humans are probability machines, each with characteristic distribution functions. Human Relations research is designed to alter the functions in some manner so as to make the decision making process of the organization more efficient. Under this assumption, it becomes theoretically possible to obtain a quantitative measure of human behavior that would be usable in any mathematical model in which it operates. It does not, however, imply impairment of the human dignity. Contrarywise, it should be no more an impairment of dignity to use quantitative techniques in tailoring a man's job than it is to use them (e.g. a tape measure) in tailoring his suit.

IV. Industrial Logistics Research Project:

ILRP is an inter-disciplinary research team drawn from persons with training in management, mathematics, engineering, (industrial and electronic), statistics and economics, engaged in a research program to develop methods of providing quantitative bases for managerial decision-making and organization.

It's work is broken down into several interrelated "task orders." One task group is working on a mathematical model somewhat similar to linear programming, but which more correctly is described as a mathematical analogy of the familiar Gantt chart. It is concerned both with the deterministic case and with the stochastic case (the latter of which is the nemisis of the Gantt Chart Technique). A further advantage of this model over the Gantt chart is that it will yield a numerical "answer" or solution to the scheduling problem. This model is perhaps the first mathematical statement of the Gantt chart. In use, it is visualized that the linear programming model would be a companion technique with our specific-assignment scheduling model as is already the case between their intuitive counterparts, shop loading and Gantt or bar chart scheduling.

Another task group is concerned with studies in automatic electronic data processing in a managerial organization. A very important recent development in this direction was made by R. G. Canning in his digital analogue of the Gantt Chart. It is an "electronic scheduler" that will take the usual data from the factory (shop status, orders, machine availability, etc) and automatically project a schedule into the future at the rate of 20 seconds of "scheduler" time for one hour of shop time. This will permit a degree of refinement and control in scheduling heretofore unimagined. But, this is only a part of the total data processing system which automatizes also such related factors as accounting and cost control, production control, inventory control, labor distribution, invoicing, etc. By looking at the managerial data processing system as a whole, it is possible to obtain these advantages at a surprisingly small cost: in a plant in which the studies were made, the saving in clerical costs alone would pay for all the equipment (including two electronics maintenance men) in just over two years. This saving does not include the advantages of better scheduling, tool control, meeting deliveries, etc. For a more complete description of this system, see (27).

Another task group is undertaking a statistical study of production-rate functions. For this, we have developed a "chronocorder" which will automatically time the operation and eliminate the time study man. The motion times will be picked up, transferred to an electronic memory and entered directly into a punched card. This is another example, I believe, of the advantage of inter-disciplinary approach to industrial engineering problem. That is, without a perspective from the use of quantitative methods in organization and scheduling we should have not appreciated the need for this statistical analysis; without an electronics engineer, we should not have been able to develop such a machine. It is hoped that the study it will make possible will contribute to overcoming the deficiencies now existing in this field.

Some of the papers and reports prepared by members of the Project are included in the Production Management exhibition. These treat the subjects mentioned here in much more technical detail. Any member of the Project would be happy to discuss our work with participants in the Institute. These reports are on file at the Project office (Administration Building) for reference of interested persons. For example, among them is a recent report by G. E. McAllister and R. T. Nelson who working on problems in work measurement from a statistical point of view have discovered certain inconsistencies in Tippett's original presentation of Ratio Delay theory and also in the present literature on the subject.

Tippett recommended a minimum time interval between observations on the same machine, and the dismissal of "long delays" from consideration as necessary precautions to obtain independent readings. By mathematical and logical arguments the authors concluded that these precautions are not only unnecessary but actually give a biased estimate for up-time and delay percentages. The interpretations of these ideas in the existing literature, rather than being an improvement, are more inconsistent with probability and sampling theory.

V. The Future of Industrial Engineering and Management

Many of the methods and techniques discussed in this paper already have been applied at the practical level with excellent improvement in profits or productivity. Many others are ready and awaiting only their adoption by practicing industrial engineers and managers; they promise to be equally useful. Others, of course, require more development before they are ready for application.

But one thing is clear, we in industrial engineering and management shall need in the future more advanced training in the basic sciences: mathematics, statistics, engineering, phychology, physiology, etc. We already have a vast background of experience and tested judgment in industrial management; we now need to accompany these with more rigorous quantitative techniques and methods. In fact, I believe we see a development of a relationship between these sciences and our profession similar to that which now exists between the basic sciences and the more "traditional" engineering. Industrial engineering and management, however, have a much broader basis and should be built on more of the sciences. We shall have to become conversant I believe, with at least the developments and contributions of the various techniques and methods surveyed here. This will imply a fundamental reorientation of the basic concepts of Industrial Engineering and Management.

We at the University hope that with the encouragement and counsel of men of industry, we shall be able to develop such broader research program for achieving this goal as well as a course of study which will permit incorporation of this broader base directly into our regular Industrial Engineering and Management educational program.

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ANALYSIS OF A CARGO-HANDLING SYSTEM[1]

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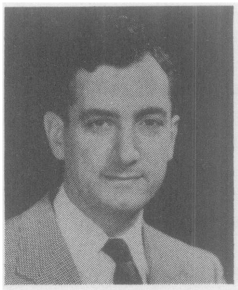


The transportation of cargo across the oceans of the world is important to the economic health and the military security of our country. Water transportation is also important to the State of California, but despite the importance of this activity, there appears to be very little formulated information. It is true that there exists a lot of "know-how" and there is a modern Maritime industry. However, it has been asserted by many people in the industry that cargo is handled just about the same today as it was in the days of the wooden sailing vessels. Cargo is handled piece by piece and is hoisted with a hook up and over the side of the ship. A notable exception is the handling of bulk cargo such as oil and ore.

The College of Engineering on the Los Angeles campus of the University of California recognized the need for action and in 1951 proposed a cargo handling research project. This proposal received the financial support of the Office of Naval Research and the Maritime Administration. The proposal was worded in broad terms as follows:

The objective of this study will be two fold:

(1) To determine by observation the time-space-energy utilized, minimum energy required, and cost relationships for the loading of ships (unloading will be considered to be negative loading).

(2) To propose changes in packaging, mechanisms, and procedures based upon minimizing costs, time and/or energy required.

Broad wording was intentional because it was suspected that the transportation system would be complex with many inter-relationships. Much evidence has been found to support this point of view. For example: immediately following World War II, larger and faster cargo ships were put into service. However, tonnage figures did not reflect the performance of the larger faster ships. This was because the rate at which material could be put through the hatch did not increase and it took longer to load the larger holds. This offset the higher speed of the ship.

The movement of cargo from a land carrier to the hold of a ship and from ship to land involves a sequence of operations, an aggregation of facilities, an expenditure of energy, and direction which together comprise the cargo handling system. The behavior of this system is dependent upon many variables and presents a wide range of technical and sociological problems. Several of the components of the system have been subjected to systematic analysis by the naval architect, terminal designer, materials handling specialist, economist, loading specialists and others. However, a systematic analysis has not been made of the system as a whole.

Therefore, although it has been necessary to focus attention on some specific topic, the "global" aspects of the problem have always been kept in mind. A rational basis for the design and operation of the water transportation system is sought. By rational basis is meant a concise and consistent definition of the system and a concise and consistent statement of the relationships between the variables. With this information one could propose changes in packaging, mechanisms and procedures in such a way as to minimize cost, time, and/or energy.

The first step was the organization of a research team that would consider the problems from many points of view. The staff has been developed slowly from three part time investigators to the present size of eleven part time men-consisting of professional chemical, electrical, industrial, mechanical engineers and students of engineering, sociology and psychology. On the basis of library research, interviews with leaders in military and civilian shipping, and observations on the piers the system has been defined as a sequence of operations, an aggregation of facilities, an expenditure of energy, and direction or control. Thus all of the men, structures, and machines involved are included.

Next the major variables were proposed as follows: (1) facility, (2) process, (3) commodity, (4) ship, (5) labor, (6) management. That is, it is proposed to predict performance (e.g. tons loaded per hour) from a knowledge of these variables. It is with the first three variables that the present study is principally concerned. It is recognized that the other variables are important. It is also recognized that there is considerable interaction between the six major variables. In order to add clarity to the exposition and to minimize the interaction between variables the following definitions have been adopted.

Facility -- the structures, equipment, and areas which are directly involved in the cargo handling system under consideration.

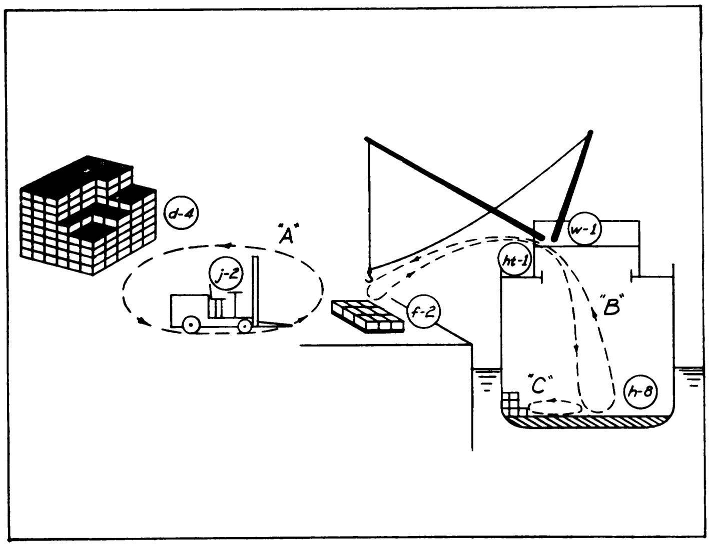
Commodity -- smallest unit of cargo individually in any portion or phase of the system.

Process -- an ordered sequence of activities and states.

The over-all plan of the study is to observe each segment of several cargo handling systems at microscopic and macroscopic levels, to analyze the data, and to generalize the results.

At this time the variables are useful only for conceptual purposes. Much more must be known about them before they can be used for prediction. In order to do this attention has been focussed on the loading and unloading operations between the point of rest on the pier and the point of rest in the hold of the ship. For example, consider the loading of boxed cargo as shown on the sketch. The process of moving cargo from the point of rest on the pier to the hold of a ship can be thought of as consisting of the three cycles A, B, and C indicated by broken lines on the sketch. In cycle A the goods are usually loaded from the point of rest on the pier onto pallets which are then moved to the side of the ship. In cycle B the goods are lifted over the side of the ship by a hook attached to a boom. In cycle C the goods are taken off the pallet and stowed. The total number and distribution of men in the stevedoring gang is usually fixed by a union-management agreement.

1. This research was sponsored by the Office of Naval Research under contract Nonr-23307.



The distribution of men shown on the sketch is typical. Four dockmen (d-4) load goods on pallets. Two jitney drivers (j-2) pick up the loaded pallets and move them to the side of the ship. Two front men (f-2) place the hooking gear on the pallet. One winchman (w-1) operates a winch which controls the movement of the boom. One hatch tender (ht-1) who is in a position to observe the activities at the side of the ship and in the hold of the ship signals the winchman and thereby guides his operations. Eight men in the hold (h-8) unload goods from the pallet and stow them. Ideally the cycle time for each of the three cycles should be equal in order to have a continuous flow of goods. However, in practice, it is more usual to find "bottlenecks" or unbalances in the cycle times.

The opportunities for the use of mechanical loading methods such as conveyors are limited by the fact that cargo ships are designed for flexibility; in other words to accomodate a wide variety of commodities. Conveyors and automatic equipment are used extensively on specially designed ships for the handling of bulk commodities such as coal, ore, grain, bananas, etc. High rates of 2,000 to 3,000 tons per hour have been achieved by designing special ships, special cargo transfer equipment and special terminals. This can be contrasted to the rate of handling general cargo which is approximately 10-20 tons per hour per hatch or a maximum of 50-100 tons per hour if all five hatches on a cargo ship are loaded simultaneously. A ship earns no revenue while it is tied up to a berth. The average ship has a fixed cost of $2,000 to $3,000 per day while in port. Revenue results from charges on the transportation of goods by water -- not for storage on shipboard at dockside. In the event of war, the extremely heavy demands on shipping and the easy targets which tied-up ships provide are two additional reasons for reducing the "turn around time" or the time that a ship is in port.

Following are several of the industrial engineering techniques which have been used to describe the operations and to establish empirical relationships between the variables, but not for the purpose of effecting immediate methods changes of operations under observation: 1. process flow charts, 2. process flow diagrams, 3. gang process charts, 4. multiple activity charts, 5. stopwatch time studies, 6. cost analyses, 7. work sampling or ratio-delay type studies, and 8. statistical analyses.

Simultaneously with the gathering of field data which includes past performance records, ideal systems or mathematical models have been postulated. These can be tested when the data are available.

For example, an electric analog computer has been conceived which would simulate the mechanical transfer of cargo shown in the sketch. The significant feature of the computer is that it does not transfer material from one point to the next unless the material is there. If it were not for this requirement cargo loading rates would be established by the ability of the longshoremen to stow cargo in the hold. Analog computers to simulate the flow of energy and the flow of information will be attempted later. Ultimately these could all be coupled together.

Another and final example of model building is an analysis which was made to determine criteria for loading a ship with heterogeneous cargo of different density in an efficient manner, i.e., selecting the cargo in such a way that the ship is full and down. A ship has two capacities, volume and weight, and earns revenue on the basis of both. Successful tramp operators load their ships so that they are full and down. However, the procedure was formulated so that the technique of analysis, in this case linear programming, could be investigated and so that the results would be available for other analyses.

In conclusion, it can be reported that cargo handling presents an interesting problem in materials handling and the tools which have been developed and used by industrial engineers have been found to be very useful.

THE EVALUATION OF AN ELECTRICAL ARTIFICIAL ARM USING MOTION AND TIME STUDY TECHNIQUES[1]

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Introduction

During the past two years, one of the tasks of the Engineering Artificial Limbs Project has been to evaluate two models of the electric arm, the below-elbow model and the high above-elbow model. The evaluation included many tests, some of which were modifications of motion and time study techniques (ref. 1 and 2). The purpose of this report is to discuss the results obtained by the use of these motion and time study techniques. The techniques have been described elsewhere (ref. 3).

Description of the Below-Elbow Electric Arm

Table 1 presents the control system of the below-elbow electric arm.

Table 1. Control System of Below-Elbow Electric Arm

Body Motion	TRANSDUCER	Hand Motion
Medial Forearm Bulge (moderate)	clutch linkage, electric	Prehension
Medial Forearm Bulge (extreme)		Opening
Pronation	pneumatic electric	Pronation
Supination		Supination
Shoulder Shrug + pronation	Bowden cable, pneumatic electric	Volar flexion
Shoulder Shrug + supination		Dorsal flexion

Hand closing and opening are mediated by medial forearm bulge. A button is depressed by the muscle mass and after approximately .25 inches of button travel, a clutch linkage has moved sufficiently to engage the prehension clutch and at the same time close a battery-motor circuit to give hand closing. Further travel of the button breaks the battery-motor circuit and after approximately .5 inches of travel a second microswitch is closed. This microswitch reverses the direction of motor drive and hand opening is obtained.

Pronating the stump works to deflate a pneumatic bladder which is mounted on the inside medial surface of the socket. The deflated air is channeled through a pneumatic tube and acts on a clutch linkage to engage the wrist rotation clutch. The air pressure also serves to trip a microswitch and forward motor drive is obtained which pronates the artificial hand. Supinating the stump, in like manner, works on a supination bladder which is mounted on the inside lateral surface of the socket. Backward motor drive is obtained with resulting supination.

Wrist volar flexion and dorsal flexion are linked with rotation. Shoulder shrug displaces a cable which engages the wrist flexion clutch. Pronation coupled with shoulder shrug results in volar flexion and supination coupled with shoulder shrug results in dorsal flexion.

Figure I illustrates the major part of the below-elbow electric arm mechanism.

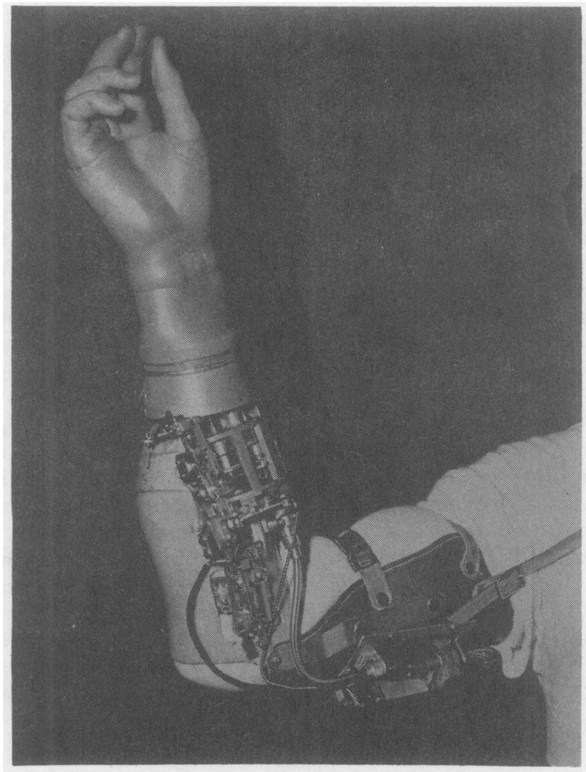


FIGURE 1. BELOW-ELBOW ELECTRIC ARM COVERS REMOVED

Motion and Time Analysis of the Below-Elbow Electric Arm

The amputee wearer of the below-elbow electric arm was trained in the standard motion and time sequences. The purpose of training is to eliminate errors (e.g., pronation instead of grasp) and to achieve performance time plateaus. Training emphasized certain design deficiencies. The subject's time and error variability was considerably greater than for three other amputees who wore conventional harness controlled artificial arms. Some reasons for variability as observed during training may be summarized as follows:

1. Change in prehension control, sensitivity as a function of degree of forearm flexion: First observations

1. Part of this report is abstracted from reference 1 of which Dr. John Lyman was co-author.

2. Acknowledgments are due Dr. John Lyman, faculty representative in charge of evaluation, Mr. William Santschi, Senior Engineering Aide, who assisted in testing the electric arm and Mr. Samuel Alderson, Project Director for the development of the electric arm.

indicated that the optimum amount of prehension button penetration into the medial forearm bulge region could be obtained for a single forearm position. This penetration, however, was not adequate for other forearm positions. A compensator, in the form of a spring attached to the medial elbow hinge and to the prehension button, was incorporated. The compensator had the characteristic of increasing the penetration of the button as the forearm was flexed. Although this system resulted in marked improvement it did not solve the problem satisfactorily.

2. Change in the space relations of control mechanism points and body control points as a function of the harness: The harness used permitted the stump to become unseated in the socket when the subject made movements to his mouth and other positions above the zyphoid level. Such movements were involved in all of the sequences with the exception of the tray, door and zipper.

3. Mechanical interaction of the three controls: Pronation and supination movements were not independent of prehension movements and flexion movements. This interaction was a particular problem in conditions of supination under load since the fingers tended to open and release the grasped object. Release of the prehension button after opening or closing had to be precisely timed in order to prevent the pronation-supination clutch from engaging and rotation from occurring. The discrimination requirements placed on the subject appeared too severe to be mastered.

4. Inadvertent tripping of controls due to conditions of external loading and forearm position: When the subject flexed his forearm under conditions of load inadvertent tripping of pronation and supination frequently occurred.

5. Unnatural neuromuscular patterns in prehension control system: To get closing the subject was required to bulge his forearm flexor mass to an intermediate position. Opening required greater medial forearm bulge. This contradicted the inherent neuromuscular patterns. In addition, when the subject desired to initiate or stop finger opening it was necessary to pass through the closing position. This often resulted in undesired finger closing.

6. Inadequate torque characteristics for rotation and flexion movements: The subject was unable to attain rotation and flexion movements under conditions of external loading which were within the requirements for the everyday living activities. With a two pound load suspended from the fingers of the hand the wrist rotation control could not be operated.

7. Speeds of motion and precision of motion control inconsistent with task requirements: For many tasks the wrist rotation speed was too fast and the control of position was inaccurate due to mechanism lags. The time required for 360 degrees of supination or pronation was 1.6 seconds and the smallest possible movement which the subject could make was approximately 75 degrees. With this speed and coarseness of control, hunting movements and "accidents" during the soup ladling and cup sequences were the rule.

Prehension speed was generally satisfactory though control was coarse. The speed for complete closing or opening was 0.7 seconds. The smallest movement possible was 7 degrees or 0.35 inches for closing and 24 degrees or 1.4 inches for opening. This difference in opening and closing sensitivity was accounted for by the two-position prehension button which required greater medial forearm bulge for opening the hand. A further effect of the two position control was illustrated by the rate at which the microswitches could be operated when the subject was instructed to operate them as rapidly as he could for a twenty second period. It was found that the closing microswitch could be operated at a maximum rate of 3.9 times per second while the opening microswitch was operated at a maximum rate of 2.8 times per second.

Speed of wrist flexion appeared to be too fast. It took 0.4 seconds for a complete flexion movement of 75 degrees and the smallest movement possible was 55 degrees for both dorsal and volar flexion. Because of this speed and coarseness of control, flexion could only be used in a limited manner for prepositioning the hand.

8. Inadequate finger geometry: The subject was unable to grasp a pencil from the table. It was also observed that round objects of an inch or more in diameter were unstable in grasp.

9. Inaccurary of grasp and effect of load on thumb: The effect of moveable thumb and opposing fingers was to decrease the accuracy of grasp. It was observed during the cup and pencil sequences that the subject had to decide on a position midway between the thumb and index finger as appropriate for grasp. This decision, if wrong, was difficult to correct due to control coarseness. Furthermore, the mechanism required that no appreciable load be applied to the thumb during closing. The effect of the applied load was to cause overtravel of the fingers.

After training, 35 mm. motion pictures were taken of 5 sequences. The arm movement sequence was the only sequence which was photographed after the learning plateau criteria were satisfied. The other sequences were photographed before awkward movements and avoidable delays were eliminated. However, as shown, these awkward movements and avoidable delays contributed little to the failure to reach time plateaus. The basic cause for performance time variability appeared to be the unreliable characteristics of the mechanism (unavoidable delays).

The following is a summary of the film analysis:

1. Body Movements (head, torso, shoulder, arm, forearm, hand)

A cursory analysis of body movements indicated that the below-elbow electric arm did not require more movement than conventional harness controlled and cineplastically controlled below-elbow arms. In fact the control of prehension and wrist rotation by implicit forearm movements (rotation of the stump and contraction of the forearm flexor mass) suggested a potential which if achieved would far surpass harness controlled prostheses in terms of the number of noticeable body movements.

For the arm movement sequence, in which the subject satisfied the plateau criteria, the total movement count index and total angular displacement index compare favorably with the indices obtained by the harness controlled and cineplastically controlled prostheses (Table 2).

Table 2. Total Movement Count (TMC) and Total Angular Displacement (TAD) for the Arm Movement Sequence.

Subject	TMC	TAD
HH-Electric Arm	42	960°
L. Q. -H. C.	46	1160°
L. Q. -C. C.	35	1250°

H. C. = Harness Controlled
C. C. = Cineplastically Controlled

For the other sequences no direct comparison is meaningful since the subject wearing the electrical arm made many movements which were due to lack of sufficient training and practice.

2. Total Therblig Times

Table 3 presents the total therblig times for the five sequences. The data show that the electric arm required more time than did the harness and cineplastically controlled arms.

Table 3. Total Therblig Times (in sec.)

	Subjects		
Sequences	HH-Electric	L. Q. -H. C.	L. Q. -C. C.
Arm Movement	5.07	5.2	4.8
Cup	13.64	11.6	9.4
Pencil	16.00	6.4	4.8
Cap Manipulation	8.68	6.6	4.6
Pencil Sharpener	21.30	13.0	12.4
Total	64.69	42.8	36.0

The times reported for H. H. are not representative for the sequences other than the arm movement sequence since H. H. had not achieved a performance time plateau. However, they do indicate that H. H., after considerable practice, still required more time than did H. C. and C. C.

3. Comparative Therblig Times

Table 4 presents comparative therblig times.

Table 4. Comparative Therblig Times (in sec.)

Transport Empty			Grasp				Release Load			
H.H.	LQ-HC	LQ-CC	H.H.[1]	H.H.[2]	LQ-HC	LQ-CC	H.H.[1]	H.H.[2]	LQ-HC	LQ-CC
1.03	1.0	1.0	4.89	1.85	.3	.4	1.35	.47	1.1	.4
.72	.8	.7	3.74	1.32	.8	.7	1.98	.65	.3	.3
.76	1.0	.9	1.94	.92	.4	.3	1.54	.18	.5	.3
1.05	.6	.8	2.28	.77	.9	.5	.50	.30	.9	.5
.70	1.0	.7	1.01	.55	.5	.5	.68	.22	.2	.4
.81	.8	.7								
.95	.7	.6								
1.11	1.0	.8								
1.21	1.9	1.3								
.72	1.5	1.1								

H. H. [1] - Present times including unavoidable delays
H. H. [2] - Present times excluding unavoidable delays

For the therblig, transport empty, no consistent differences appear between the three subjects. Transport empty does not require any prosthetic movement and the lack of consistent differences suggests that the restriction of body movement by the prosthesis did not effect any marked differences between the subjects.

Comparative grasp times shows a marked consistent difference between the electric and other arms if we consider unavoidable delay time.* The difference is greatly reduced if we omit unavoidable delay time. The same relations are generally true for comparative release load times.

4. Movement, U. D. and A. D. Times

Table 5 presents the times for prosthetic movements, unavoidable delays and avoidable delays. Several interesting relations can be seen.

a. Out of the 36 movements tabulated only four represent avoidable delays involving a total time of 0.61 seconds. This time is only 4.5 per cent of the time spent in prosthetic movements.

b. Only 7 out of the 36 movements did not involve a measurable unavoidable delay time. The unavoidable delay time represents 117 per cent of the time spent in prosthetic movements. If the total of 16.34 seconds spent in unavoidable delays were to be subtracted from the total therblig time the difference between H. H. and H. C. -C. C. would be reduced by a considerable amount.

Table 5. Unavoidable Delay and Avoidable Delay Times

Desired Movement	Obtained Movement	Movement Time	U.D. Time	A.D. Time	Desired Movement	Obtained Movement	Movement Time	U.D. Time	A.D. Time
o	o	0.50	0.00	0.00	o	o	0.18	1.36	0.00
c	c	0.18	0.00	0.00	c	c	0.67	0.25	0.00
c	c	0.40	2.27	0.00	s	s	0.37	0.12	0.00
o	o	0.47	0.88	0.00	s	p	0.08	0.10	0.08
c	c	0.29	0.00	0.00	s	s	0.30	0.00	0.00
p	p	0.53	0.00	0.00	o	o	0.26	0.56	0.00
o	o	0.69	1.04	0.00	c	p	0.12	0.55	0.12
c	c	0.63	1.38	0.00	c	c	0.51	0.36	0.00
s	p	0.25	0.08	0.25	o	o	0.30	0.20	0.00
s	s	0.83	0.30	0.00	p	p	0.35	0.00	0.00
o	o	0.35	0.54	0.00	c	c	0.55	0.46	0.00
c	o	0.30	0.79	0.00	o	o	0.22	0.46	0.00
p	s	0.16	0.13	0.16	s	s	0.29	0.00	0.00
s	s	0.25	0.18	0.00	c	c	0.30	0.56	0.00
o	o	0.67	0.46	0.00	p	p	0.63	0.62	0.00
c	c	0.25	0.63	0.00	o	o	0.20	0.33	0.00
p	p	0.67	0.46	0.00	s	s	0.39	0.09	0.00
s	s	0.42	0.65	0.00	c	c	0.37	0.24	0.00
					Totals (both columns)		13.93	16.34	0.61

U.D. = unavoidable delay
A.D. = avoidable delay
o = open hand
c = close hand
p = pronate wrist
s = supinate wrist

c. It is suggested that the unavoidable delay time was the greatest contributor to the difficulty H. H. had in reaching time plateaus. Since unavoidable delay time appears to be highly variable it is probable that time plateaus could never be achieved.

Recommendations for Improving the Below-Elbow Electric Arm

On the basis of the motion and time studies and other tests which substantiated the obtained results the following recommendations were made to improve the design of the below-elbow electric arm:

1. Minimize terminal mechanical lag:

If terminal mechanical lag continues after the body movement stops, as was the case with the supination control, hunting movements are probable, since the mechanism will continue to move if the subject continues to make body movements in an attempt to correct errors.

The off-on control essentially presents a velocity tracking situation to the amputee. The subject makes the battery-motor circuit and by means of visual or time cues judges the position at which he wishes to stop the mechanism. Experimentation with tracking behavior indicates that the magnitude of error is proportional to the mechanical lag (ref. 4). It is thus desirable to minimize mechanical lag.

2. Limit body movement overshoot:

This would have the effect of reducing the time that the circuit is made, and would serve to allow smaller extents of movement. To do this effectively, it would be necessary to study body movement reversal time, switch overshoot and switch reversal time. The force characteristics of the switch, or of the linkage between the switch and the body movement, will determine the degree of body overshoot. A spongy system will permit a proportionately greater amount of overshoot than a rigid system. By start-

* Unavoidable delay time is defined as time the subject spent in trying to obtain a specific prosthetic movement but failed to get any movement.

ing the "on" part of the cycle near the end of the body movement or by making a definite increase in load on the body part when the switch is actuated, overshoot may be reduced.

3. Minimize initial and terminal body movement lags: The biomechanics of body movements indicate that if the movement is made against no load, initial and terminal body movement lags are not a function of the distances traversed. The time it takes to travel increasing distances remains relatively constant due to an increased velocity of movement (ref. 5 and 6). If movement is made under load, then the time for making the movement increases proportionately to the amount of load (ref. 7). This information suggests the following design criteria for off-on controls:

a. The initial and terminal movement lags should be incurred under conditions of no load. This would permit maximum velocity and the distance necessary to travel to make the switch can be made extensive enough to avoid inadvertent actuation without significant increase in time. Under these conditions maximum speed of body movement would be obtained since ballistic movements could be used effectively (ref. 8).

b. Once the switch is contacted, the load should be applied instantly. This suggests a rigid system which would minimize body movement overshoot. The effect of a rigid stop would also aid in imparting the body part with momentum for the reverse movement and would thereby decrease body movement reversal time.

4. Investigate the possible utilization of the lateral forearm bulge for opening movement control to replace two position prehension control.

5. Investigate the shape and size of the prehension button and button spring force in relation to their effects on the control cycle and stability of control at various arm positions and as a function of load.

6. It is suggested that the built-in motion be made prehension rather than wrist rotation as at present.

7. Base speed of prosthetic movement on cosmetic appearance. It is suggested that a reasonable design speed would be the mean speed of movement in a variety of everyday living activities weighted for the frequency of the activity.

8. Limit finger travel to one and one-half inches by means of a stop on the gear rack or an increase in the strength of the thumb follower spring.

9. Eliminate interactions between prosthetic movements.

10. Reposition finger pads in order to improve grasp stability.

11. Restrict wrist rotation movement to 90° supination and 90° pronation.

12. Minimize stump changes after fitting by providing pre-fitting exercises for the amputee which are designed to develop the muscles of the control sites.

13. Assess the force characteristics of the prosthetic movements in relation to everyday living requirements.

14. Examine harness and socket design in relation to effects on control stability.

15. Use self-actuating controls in preference to controls in which selection and actuation are separate.

Description of the High Above-Elbow Electric Arm

The high above-elbow electric arm is intended for amputees who have approximately twenty to thirty percent of their humerus remaining. The stump, therefore, is not of sufficient length to control a conventional above-elbow harness controlled artificial arm, but has sufficient movement to operate an electric control keyboard. Figure 2 presents an amputee who was fitted with the high above-elbow electric arm.

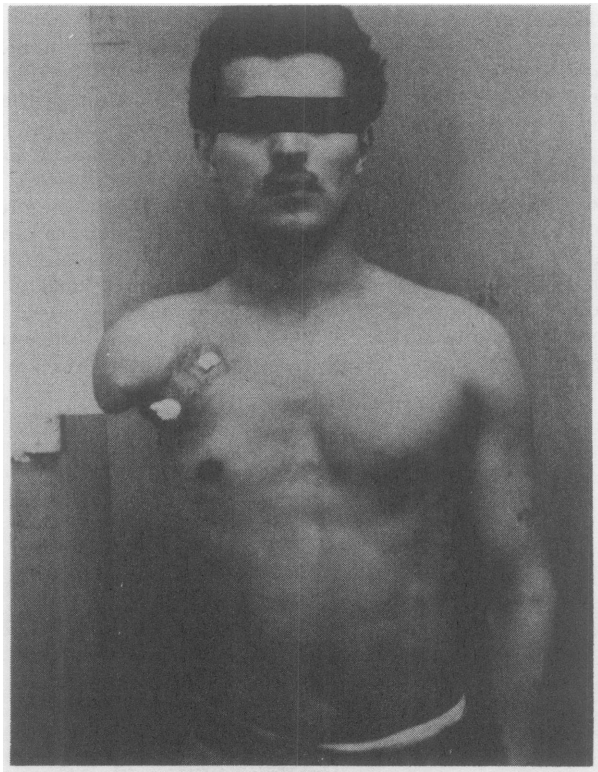


FIGURE 2. HIGH ABOVE-ELBOW AMPUTEE TO BE FITTED WITH THE ELECTRIC ARM

The control system for the high above-elbow electric arm is outlined in Table 6.

Table 6. Control System of High Above-Elbow Electric Arm

Body Motion	Transducer	Prosthetic Movement	
Shoulder Elevation	mechanical (harness operated)	coupled forearm flexion and arm abduction	
Stump Extension and/or Muscle Bulge	mechanical (push button) electrical (solenoid) mechanical (friction plates)	alternate elbow locking and unlocking	
Pectoral Bulge	mechanical (push button, lever-cable, lock pin) inertia, gravity	turntable	
Stump and Shoulder Movement			
1. Depression of closing plunger	mechanical pneumatic (prehension clutch engaged) electric	forward motor drive	hand closing
2. Depression of opening plunger		backward motor drive	hand opening
3. Depression of pronation plunger	mechanical pneumatic (rotation clutch engaged) electric	forward motor drive	pronation
4. Depression of supination plunger		backward motor drive	supination
5. Depression of wrist flexion plunger	mechanical, pneumatic (wrist flexion clutch engaged) electric	forward motor drive	wrist flexion
6. Depression of wrist extension plunger		backward motor drive	wrist extension

As can be seen from the table, the electrical features are the elbow lock control and the six prosthetic hand motions. The elbow lock control is mediated by stump extension and/or bulging of the scapular muscles. A button is depressed which closes a battery-solenoid circuit. The solenoid mechanically places pressure on a series of friction plates which lock the elbow. The prosthetic hand motions are mediated by stump and shoulder movement. Six cylinders are positioned on a shoulder control panel. Depression of the cylinder plungers, one for each of the six prosthetic motions, forces air through pneumatic tubes to a system of bales contained in the prosthetic forearm section. Pneumatic bladders mounted on the bales expand with the incoming air and serve to engage the clutch and to trip a microswitch which closes the battery-motor circuit. As in the below-elbow electric arm, three clutches, prehension, rotation, and flexion, serve the six hand functions, as forward and backward motor drives yield antagonistic motions. Figure 3 presents a dorsal view of the forearm mechanism showing the motor and bale system.

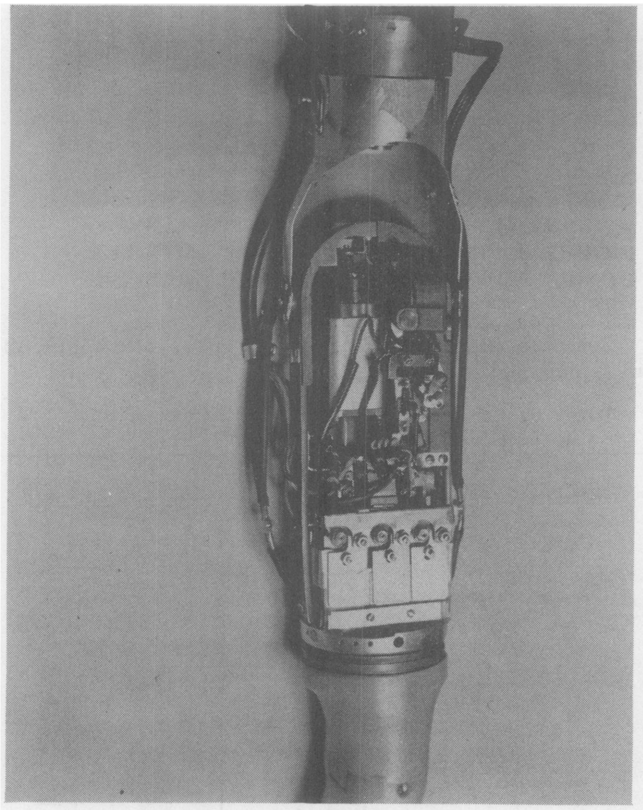
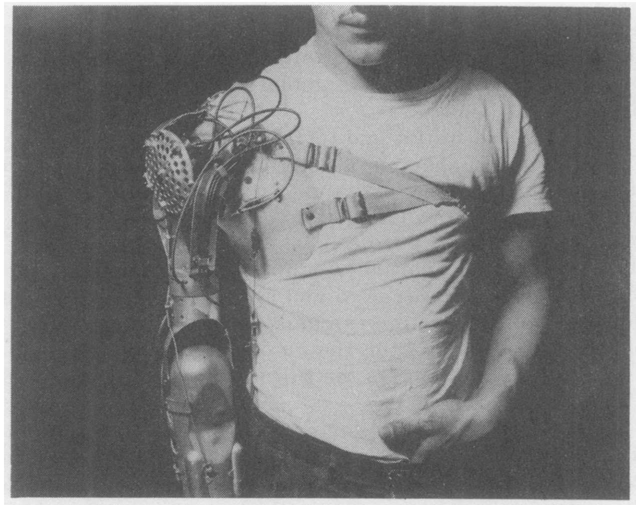


FIGURE 3. DORSAL VIEW OF HIGH ABOVE-ELBOW ELECTRIC ARM FOREARM MECHANISM, WITH COVER REMOVED

Figure 4 presents the amputee wearing the arm and figure 5 shows the shoulder control panel as it fits the amputee.



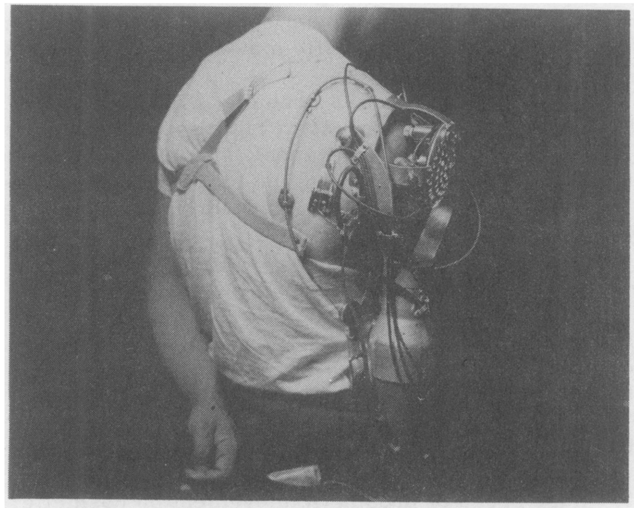


FIGURE 4. AMPUTEE WEARING THE HIGH ABOVE-ELBOW ELECTRIC ARM

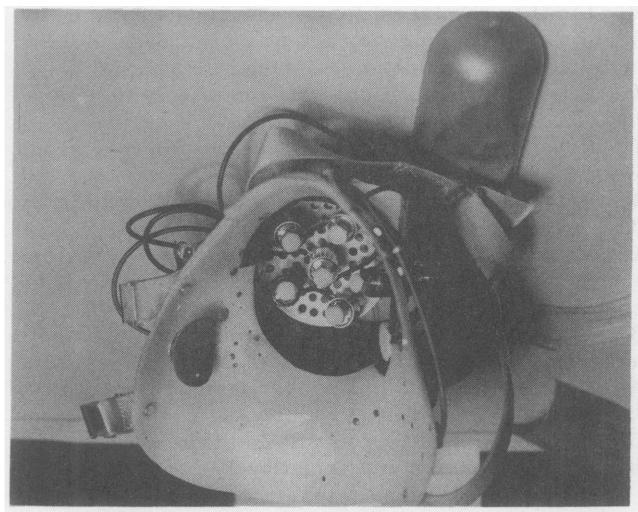


FIGURE 5. INNER VIEW OF THE HIGH ABOVE-ELBOW ELECTRIC ARM SHOULDER CAP SHOWING THE CONTROL PANEL AND HAND OPERATING CYLINDERS AND PLUNGERS

Motion and Time Analysis of the High Above-Elbow Electric Arm

Two amputees were tested wearing the electric arm. They were also tested with conventional harness controlled prostheses. Training in the standard motion and time sequences were administered. The following is a summarization of the results.

1. The electric arm permits a closer approximation to non-amputee movement than does the conventional prosthesis.
2. Performance time and error variability as indicated by the standard deviation is greater for the electric arm than for the conventional prosthesis. Mean performance time and error is also greater. During the time allotted for testing performance plateaus could not be achieved.
3. Certain of the recommendations made for the below-elbow electric arm with respect to mechanism changes, have been considered in the design of the high above-elbow electric arm. This has led to increased mechanism stability and reliability.
4. A significant deterrent to coordination of electric arm movements was the problem of inadvertent actuation of controls. Such improvement in mechanism reliability as has been observed, tends to emphasize the lack of fundamental data relevant to the stump-control problem. This problem was related to the positioning of hand motion actuation plungers on the shoulder control panel, and the forces and excursions required to operate the plungers. The need for fundamental research to determine the optimal system was made especially apparent by the persistence of avoidable delays. The control task, in brief, is too difficult for the amputee and the design of the electric arm is not within the tolerances of the amputee's sensory-motor capabilities.

Analysis of the Role of Motion and Time Study in the Evaluation of the Electric Arm

The preceding sections suggest that the role of motion and time study is that of a "trouble-shooting" technique. Design deficiencies are highlighted by the stringent training schedule which is maintained prior to photographing the standard sequences. Therblig and body movement analyses of the film afford a means of studying the pattern of movement in detail. From the film analysis of quantitative comparison between two types of artificial arms can be made. The recording of avoidable delays, unavoidable delays, grasp time etc., yields pertinent information for a detailed appraisal of prosthetic function with respect to everyday living requirements.

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QUALITY CONTROL SESSION

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DISCOVERY SAMPLING: A NEW APPROACH IN INSPECTION

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The scope of the term "Quality Control" has been broadened through practice over the past ten years to include all manner of inspection techniques including inspection itself. Sampling plans are a part of this broad interpretation.

The application of conventional sampling plans to a large variety of short runs creates a volume of records that is out of proportion to the economic gain from the application of these plans.

At the present time this is the prime problem confronting the job shops and the airframe industry, when an attempt is made to install a Quality Control program.

Lack of a suitable technique is preventing the acceptance of Quality Control and Sampling methods in many plants. Since 1942 Lockheed has tried or studied each new statistical inspection technique in search of a suitable approach to Statistical Quality Control and Sampling. As each technique subsides in economic popularity it rekindles the desire for a simple method. "Simple to teach, easy to use, no square root, no formulas, no tables, no monograms, no records - just results". This is an almost impossible specification, but the problem can be separated into two parts:

1. A theory to satisfy the statistician.
2. Just results - to satisfy production and inspection, supervision and management.

The method of DISCOVERY SAMPLING is a plan, simple for the inspector to use, that will yield a quality level that can be specified.

APPLICATION OF DISCOVERY SAMPLING

IF A PART IS APPROVED FOR SAMPLING, TEN PARTS SHALL BE SELECTED IN A RANDOM MANNER AND INSPECTED FOR EACH LOT. IF NO DEFECTS ARE FOUND, THE LOT IS ACCEPTED. IF ONE OR MORE DEFECTS ARE FOUND, THE LOT IS DISPOSITIONED AS DISCREPANT MATERIAL.

DISPOSITION OF DISCREPANT MATERIAL

If discrepant material is discovered in a lot one of three courses may be pursued:

1. Return the lot to Production for screening.
2. Screen the lot.
3. Inspect a total of 100 parts from the lot and send the good and discrepant material (found in the 100) to Material Review for disposition.

Material Review dispositions are:

1. Use as is
2. Rework to conform
3. Rework to variation
4. Scrap

That is the statistical part of the plan from the point of view of the inspectors. It yields theoretically a average of less than one-half of one percent discrepant material in the stockroom.

A PART MUST BE APPROVED FOR SAMPLING

If no approval for sampling exists, 100% inspection is required. It was found that the Inspection Supervisor directly in charge of a group of inspectors was the most informed individual in a practical sense. He is authorized to approve a part for sampling by signing an Inspection Instruction Record on which he lists characteristics that require 100% inspection. The Inspection Instruction Records are filed by part number and are given to the inspector with the parts, the print, and the necessary tools for inspection. Inspection Instruction Records are used even when 100% inspection is required (i. e., no sampling).

WHAT STATISTICAL RECORDS ARE NECESSARY?

A weekly record of the disposition of the lots presented for inspection is kept for each inspection area. The part number is entered in one of four columns:

1. Accepted
2. Incomplete
3. Partially discrepant
4. 100% discrepant

If the lot was sampled the letter (S) is prefixed in a column provided. The percentage of partially discrepant lots is used for the statistical requirements for the application of Discovery Sampling.

INCREASED PROTECTION

Some characteristics of a part require increased protection. To achieve this 25 parts per lot are inspected for hardness, flaws, and thickness of sheet metal. If a sample of 25 will not give sufficient protection, then 100% inspection is required for specific characteristics.

WHAT ARE THE RISKS INVOLVED?

Any sampling plan involves a risk of accepting discrepant material. The statistical problem is to measure this risk and express it in numbers. There are two kinds of risks: (1) the chance of accepting a single lot with the fraction defective p; (2) the chance of accepting an average fraction defective k.

CHANCE OF ACCEPTING A SINGLE DISCREPANT LOT

Knowledge of the chance of accepting an individual lot with fraction defective "p" is important to the Inspection Supervisor who approves parts for sampling. It answers the following question: What is the chance of accepting a lot that is 10% discrepant or 20% discrepant, etc. ? This information is presented for the Inspection Supervisor as a curve called an operating characteristic curve, or, simply, an OC curve. (The formula for an OC curve is $Pa = (1-p)^n$ where "n" is the sample size and "p" is the fraction or % defective times 100). These OC curves are given in the texts on Quality Control and Sampling, and in MIL-STD. 105A, the "Military Standard Sampling Procedures and Tables for Inspection by Attributes".

The use of an OC curve alone is frightening because it states that for a sample size of 10, a lot that is 10% discrepant will be accepted 35% of the time, and a 20% discrepant lot will be accepted 10% of the time. What the OC curve doesn't answer is "how frequently a lot occurs that is 10% defective". Single, double, and multiple sampling plans require a process average on every part to give a measure of the probability of occurrence of lots containing discrepant material. This is satisfactory for a plant making long runs on a few standardized items that have a quality level distributed about an average fraction defective. Aircraft quality is not so distributed and involves more than 100,000 different parts per model, with runs from 30 to 300 units per lot, and the same part number may be introduced to Production once every month or as infrequently as every three months or more. By sheer weight of record maintenance alone, the average quality level approach eliminates the advantage of sampling as compared with 100% inspection.

A NEW CONCEPT

It is at this point that Discovery Sampling introduces a new concept. Since the volume of data by part number is so great, a particular area such as the sheet metal department is considered statistically as a single process. It is agreed that the parts are of different shape, but they are made by a crew of men on a type of machinery and they have common characteristics independent of part number. Each lot of different parts constitutes a sample from this process. This is an acceptable concept from a statistical point of view and the average number of partially discrepant lots from a given area is a measure of the quality level within that area from the standpoint of sampling risk.

FREQUENCY OF OCCURRENCE OF PARTIALLY DEFECTIVE LOTS PRESENTED TO INSPECTION:

Lots that are neither wholly good nor wholly bad are "partially defective" and contain some fraction of defective "p". A study was made of more than 25,000 lots presented to different inspection areas. Receiving, Functional Test, X-Ray, Fabrication, and Sub-Assembly areas were included.

The same characteristic type of distribution curve was found in all areas. A curve was fitted to these data to provide a compact formula for the distribution of partially defective lots presented to Inspection.

The data and the curve are shown in Figure I. The vertical scale is assigned in such a manner that the area under the curves equals 1 or certainty in the statistical sense.

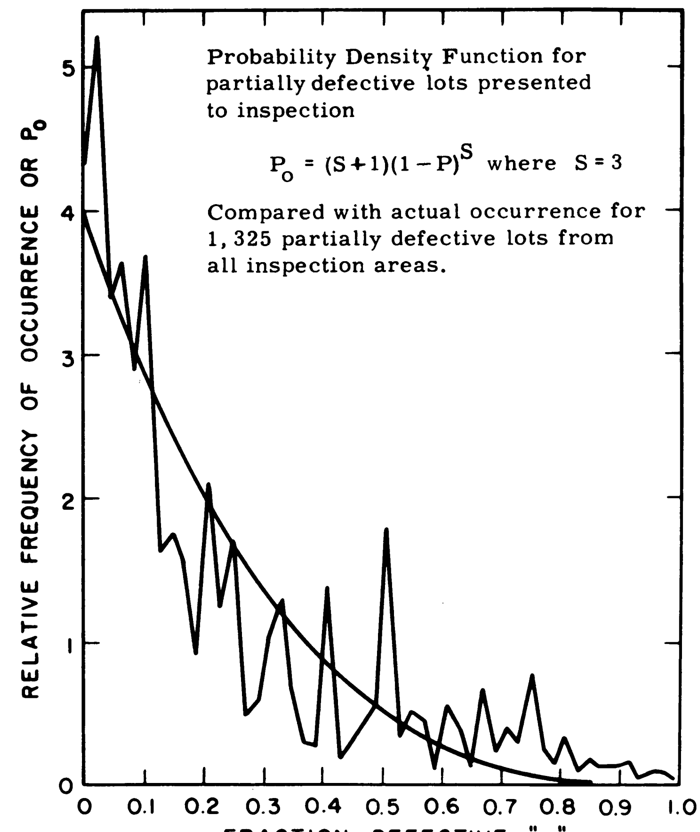

FIGURE 1

PERCENTAGE OF DISCREPANT MATERIAL IN STOCK

Using the assumptions that partially defective lots presented for inspection occur to the extent "A" and are distributed according to the curve given in Figure I, this incoming material is then sampled by inspection to the extent "n". The following relationship exists:

$$A = \frac{(S+2)(N+S+1)(N+S+2)}{(N+S+1)(N+S+2)\left[1-\frac{1}{K}\right](S+1)(S+2)}$$

Where K is the fraction of discrepant material in stock and S is the parameter related to the distribution of partially defective lots.

Assigning 0.002 for K and 10 for "n", "S" was allowed to vary and the resulting value for "A" plotted. This gives the curve shown in Figure II.

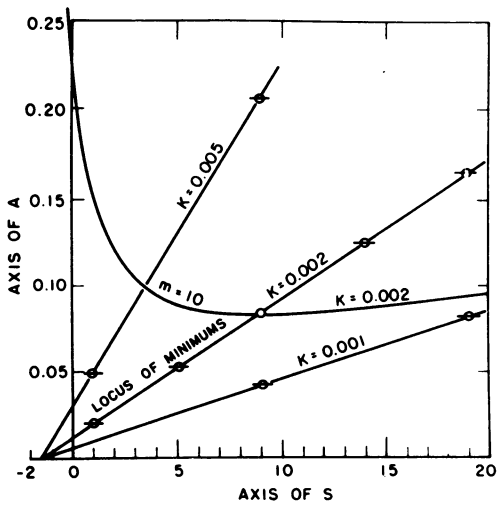

FIGURE 2

This curve had a minimum at S=n-1. Holding K at 0.002 and substituting n, n-1 and n-2 for S and assigning to "n" the values 2, 6, 10, 15 and 20, a minimum always occurred at S= n-1. The curve is generally so flat at this point that several significant figures are required to detect the variation. A straight line through this set of minimum points is

$$A = 0.008(n+1/2)$$

The same method was applied for K = 0.005 and K= 0.001 giving two additional straight lines. These three straight lines passed through the common point A=0; S= — 1-1/2. "S" was assigned the most severe value (n-1) yielding the general relationship

	RELIABILITY
$A>4K(n+\frac{1}{2})$	Use nearest 1/10% or two significant figures
$n<\frac{A}{4K}-\frac{1}{2}$	Use nearest whole number
$K<\frac{A}{4n+2}$	Use one significant figure, e.g. .002, .005, etc.

A general indication of the reliability for the determined value is given for each variation of the formula. These restrictions are satisfactory for practical work. Mathematical verification supported the formulae and gave the actual error terms, but full consideration of the theory at this point is prohibitive.

The last form for this relationship states that the fraction of discrepant material going to stock on an average is less than the percentage of partially defective lots - divided by - 4 times the sample size used by the inspector - plus 2.

The formula for the fraction of discrepant material in stock provides a basis for decision relative to the number parts per lot that should be in the inspection sample. To illustrate: If 8.4% of the lots in a production area are partially defective (as defined) and it is desired to hold the average for discrepant material in stock to 0.002 then

A= .084
K= .002, and

$$\text{The Sample Size "n"} = \frac{.084}{4(002)} - \frac{1}{2} = 10$$

A sample size of 10 will give the desired result as long as the average occurrence of partially defective lots is less than 8.4%. A chart by weeks for the percentage of partially defective lots constitutes the only necessary record and provides the value for "A".

There are areas like the punch press department where the fraction of partially defective lots is extremely low and a sample size of 2 would be sufficient. We have standardized on a sample size of 10 for all Production Departments to simplify application and administration.

The remaining unanswered question is - "Does this relationship still hold when the actual distribution for partially defective lots is used, instead of the curve substituted for it in the mathematical analysis?" Ref. Figure I. The results are given in the following Table:

TABLE I

AVERAGE DISCREPANCIES IN STOCK

	USING THE FORMULA	USING THE ACTUAL DATA
Sample Size 10	0.00238	0.00184
Sample Size 4	0.00558	0.00481

The Formula is more conservative

The sample size of 4 is the most severe test because at this point the combination of adverse conditions is at a maximum.

Discovery Sampling is a practical sampling technique for the inspector. It yields a simple formula for average discrepancies in stock, and the concepts and theory open a new territory for the research mathematician.

DISCOVERY SAMPLING FOR SMALL LOTS

Many instruments and Functional Test items, like fuel pumps, are stocked after receipt without inspection because of problems related to packaging and preservation. These parts are removed from stock in sublots and tested before release to production.

If a large lot not readily available is divided into small sublots that are inspected, it is intuitively evident that the sample required from each sublot should be smaller than the sample required for the large lot, if the required degree of assurance is the same. To be convinced, it is only necessary to take the case where the sublot lot size is 10 and the sample size for the large lot is 10. This is 100% inspection and certainly yields a greater theoretical assurance than any sampling plan. In the Functional Test Department where one test may take as long as 15 minutes, a reduction of the sample size for a small lot is highly desirable from an economic standpoint.

Small lots of size "L" may be considered as subgroups from a large lot with a fraction defective "p". By chance these small lots will contain 0, 1, 2... L defectives. If these small lots are sampled by the inspector to the extent "r", the quality level that results can be expressed. The previous discussion of Discovery Sampling for large lots led to an expression for the quality level that results in stock when a large lot is sampled to the extent "n". When the small lot and large lot expressions are equated the relationship of the sample size "r" for a small lot "L" to the sample size "n" for the large lot is established. The equation is:

$$\frac{L-r}{L(r+s+1)(r+s+2)} = \frac{1}{(n+s+1)(n+s+2)}$$

Table II gives a useful set of solutions for this equation.

TABLE II

REDUCED SAMPLE SIZE (r) FOR SMALL LOT OF SIZE (L), (GIVEN IN THE BODY OF THE TABLE) IF SAMPLE SIZE (n; s=0) IS USED FOR A LARGE LOT

r	n=5	n=10	n=15	n=20	n=25	n=30
1	1-2	1	1	1	1	1
2	3-5	2-3	2	2	2	2
3	6-11	4-5	3-4	3	3	3
4	12-43	6-7	5	4-5	4	4
5	Over 43	8-10	6-7	6	5-6	5
6		11-15	8-9	7-8	7	6-7
7		16-23	10-12	9	8	8
8		24-43	13-15	10-11	9-10	9
9		44-140	16-19	12-14	11-12	10-11
10		Over 140	20-25	15-16	13-14	12
11			26-35	17-20	15-16	13-14
12			36-52	21-24	17-18	15-16
13			53-91	25-29	19-21	17-18
14			92-286	30-36	22-24	19-20
15			Over 286	37-46	25-28	21-23
16				47-62	29-33	24-26
17				63-90	34-39	27-29
18				91-155	40-47	30-33
19				156-482	48-57	34-37
20				Over 482	58-72	38-43
21					73-96	44-49
22					97-138	50-58
23					139-237	59-69
24					238-728	70-83
25					Over 728	84-104
26						105-137
27						138-196
28						197-334
29						335-1024
30		(S=3)				Over 1024

Formulae exist for the cases where defects are allowed in the large lot sample. The equation where one defect is allowed in the sample of "n" is

$$\frac{L - r}{L(r+s+1)(r+s+2)} = \frac{s+3n}{(s+n)(s+n+1)(s+n+2)}$$

ACTION TAKEN FOR DISCREPANT SMALL LOTS

The small lot "L" is inspected 100% if a defect is found in the reduced sample "r". Since the small lot is from a large lot in stores we are in trouble from a procurement point of view if the large lot is defective. It is desirable to know when a stock check is required. Table III gives the criteria for making a stock check.

TABLE III

IF THE SMALL LOT CONTAINS MORE THAN THE CRITICAL NUMBER OF DEFECTS "D" THE PARENT LOT WILL BE GREATER THAN 10% DEFECTIVE MORE THAN 90% OF THE TIME

SMALL LOT SIZE	CRITICAL NUMBER OF DEFECTS "D"	SMALL LOT SIZE	CRITICAL NUMBER OF DEFECTS "D"
1 to 2	0	52 to 58	8
3 to 8	1	59 to 66	9
9 to 14	2	67 to 74	10
15 to 21	3		
22 to 28	4	75 to 82	11
29 to 36	5	83 to 90	12
		91 to 99	13
37 to 43	6	100 to 107	14
44 to 51	7	108 to 116	15

This table was constructed using Campbell's approximation to the incomplete Beta function based on the Poisson distribution, Page 185 in Simon "An Engineer's Manual of Statistical Methods".

DISCOVERY SAMPLING BY VARIABLES

Up to this point we have been discussing Discovery Sampling by "ATTRIBUTES". The word "ATTRIBUTES" conveys the meaning that a part is either good or bad with no measure of the degree to which this is true. If the degree to which a characteristic of a part is good or bad can be measured, this measure of the characteristic is called a variable. This added information can be put to use to further reduce the amount of sampling necessary to achieve a desired degree of quality assurance.

The process for getting this extra assurance is unbelievably simple. An example:

The following five parts were selected at random from a lot and arranged in order of size. The dimension of the part is specified as 1 inch with the tolerance of ±.010.

	DIMENSION
Upper Limit of Tolerance	1.010
	1.006
	1.002
Ordered Sample	1.001
	.998
	.993
Lower Limit of Tolerance	.990

If either the largest or smallest value exceeds the tolerance hold the lot for disposition. Otherwise, discard the highest and lowest measurements, i.e., (1.006 and .993) and difference the remaining extreme measurements.

	1.002
	- .998
Difference	.004

Subtract this difference from the smallest remaining measurement

	.998
D ;	-.004
	.994

If this number is greater than the lower tolerance, accept the lot as being above the minimum.

Next, add the same difference to the largest remaining measurement

	1.002
D ;	+.004
	1.006

If this number is less than the upper tolerance accept the lot as being below the upper tolerance. If either of the above numbers exceed the related tolerance, the lot is held for disposition.

The above plan is described as a 1-3-1 plan, which means exclude the extremes of a sample of five and work with the extremes of the middle three measurements.

In a like manner 2-6-2 means exclude the two largest and the two smallest measurements in a sample of 10 and work with the extremes of the middle six measurements. Such a plan has a determinable OC curve or operating characteristic curve. The OC curve for the 1-3-1 plan is given in Figure III.

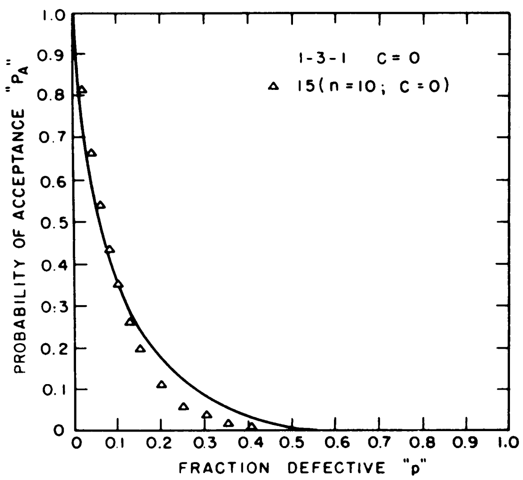

FIGURE 3

The Operating Characteristic Curve tells what a sampling plan will do. The variable plan 1-3-1; c=0 will accept 70% of the lots that are 2% defective, 34% of the lots that are 10% defective, and so on.

The 1-3-1 plan for variables gives approximately the same quality assurance as the attribute plan for a sample size of 10 and acceptance number 0. This latter OC curve is shown as X'5 Figure III. The saving to Inspection is 50%.

To illustrate the effect on the operating characteristic curve as the sample size for variables increases, four simple OC curves were computed. These are shown in

Figure IV.

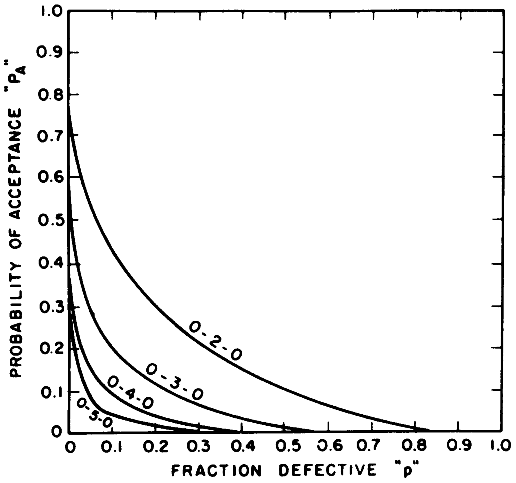

FIGURE 4

Multiple sampling by variables is practical. The operating characteristic curve for the combination of the 0-3-0 plan and the 1-3-1; c=0 plan is shown as the dashed line in Figure V.

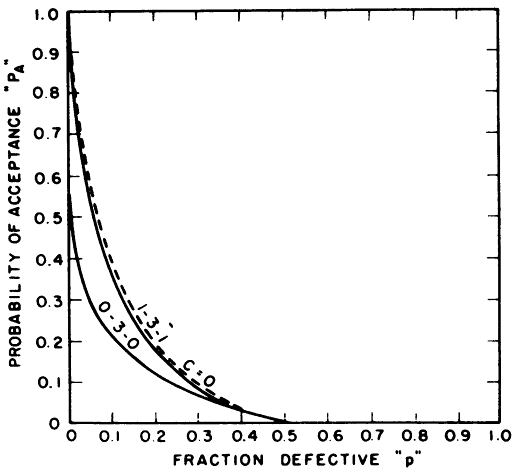

FIGURE 5

This plan yields an additional saving to Inspection of 40% on high quality products and operates as follows:

First inspect three parts on the basis of the 0-3-0 plan. If discrepancies are indicated inspect two more parts and apply the 1-3-1; c=0 plan and accept the lot or hold for disposition as indicated.

The effect of using different truncated ranges, with the total sample size fixed at 10, is illustrated in Figure VI.

Defects occurring in the dimensions excluded from the truncated range were excluded from consideration for the OC curves in Figure VI. This type of plan is a true variable plan. When the restriction is added that only "c" defects are allowed in the dimensions excluded from the truncated range, a combined attribute and variable plan exists. The effect of changing the defects allowed for the 3-4-3 variable plan is illustrated in Figure VII.

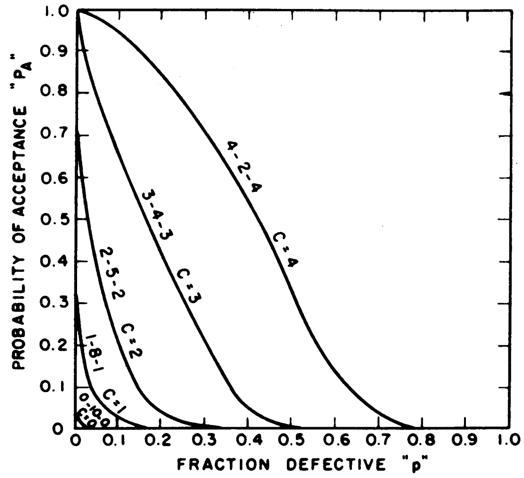

FIGURE 6

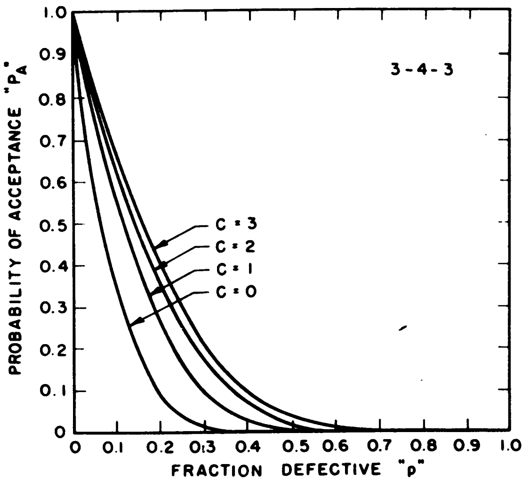

FIGURE 7

The curves for Figures 3, 4, and 5 were computed with a formula and checked with drawings from a normal universe of 1,000 chips with the interval of 0.25.

Figures 6 and 7 were developed from 210 drawings of 10 chips each from the normal universe.

Discovery Sampling techniques provide a powerful set of sampling tools that are readily available for your use. To use them you need only to know addition and subtraction.

Discovery Sampling techniques are the result of an intensive research program supported by Mr. George H. Prudden, Lockheed's Director of Quality Control. William H. Wahrhaftig, Robert A. Schafer, Verne S. Myers, and Ben K. Gold contributed heavily to the development, and Seymour Sherman helped with the mathematical logic in the tight spots. The inspiration came from the discussions at a regular meeting of the American Society for Quality Control, where Dr. Leo A. Aroian presented a paper entitled "The Effectiveness of Quality Control Charts". The Inspection supervisors deserve a full measure of credit for applying the pressure to get the job done to their liking.

Several copies of the original papers that cover the theory of Discovery Sampling in all of its mathematical splendor are available for study.

DISCOVERY SAMPLING: A NEW APPROACH IN INSPECTION - - DISCUSSION

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When I was asked to discuss the paper presented by Mr. Crawford tonight I asked, What is discovery sampling and what are its advantages? Where does it apply? Can I use it? etc...

Mr. Crawford has told us what it is and answered most of the other questions that might be asked. That is, the questions that might be answered in the time available here tonight.

So, by way of discussion, I would like to review with you some of the impressions I had as I read the paper and some of the theory behind it. First I find that Mr. Crawford looks at stores rather than the individual lots or Part Numbers that go to make up Stores inventory. This tends to be the top management view point. Management is not apt to be concerned about "a part" or "a lot" they will more likely ask "of all the money tied up in Stores Inventory, what fraction represents defective material as a result of the sampling plan?"

This is a good question and a difficult one to answer under most circumstances. A scheme has been approved to limit the percent defective in stores and answer the question "how much?"

This concern with the fraction defective in stores means that "Discovery Sampling" is concerned with protection for stores as such and not with limiting the percent defective for a given part number. This is a necessary result of looking at a production area as a single system of causes and the desire to minimize record keeping.

Under these circumstances the Plan does not provide an acceptance criterion for any percent defective. It is rather concerned with the probability of discovering a defective, if it exists, and therefore of screening the lot and introducing into stores a 100% good lot to dilute the percent defective. This is a satisfactory approach if lots are small. If you have general protection that will maintain stores at less than 1% or 1/2% or .2% defective then you will have only occasional bad lots in stores and you can afford to handle those few as an emergency when they are discovered. If there are only a few bad lots and they are small you can afford to re-run them as a special case when they are discovered rather than when they are produced and still be ahead of the game. Because, you see, the alternative would be a 100% inspection to discover those few bad lots when they are produced and re-run them at that time. In concerning himself with Stores and what gets into stores, Mr. Crawford has introduced a slight change into the meaning of "Probability of Acceptance." When he says "Probability of Acceptance" he means the probability of a given affect on stores. The probability of acceptance does not depend upon whether a lot is in fact submitted for inspection. It depends only upon the sample size, the acceptance number and the percent defective. However, the probability that a particular kind of lot will arrive in stores depends on whether or not it is made and submitted for inspection. Mr. Crawford has discovered empirically that lots submitted for inspection, in general, conform to a $(1-P)^S$ curve.

This empirical determination has two advantages. First, where others consider all possible conditions (even the possibility that only the most critical percent defective will be submitted) and base their guarantee of protection on the <u>worst conceivable</u> case, Mr. Crawford uses the actual conditions and bases his assurance on the <u>worst expected case</u>. The worst expected case is much better than the worst conceivable case.

Secondly, having the distribution of submitted lots known makes it possible to keep process averages on production areas in terms of percent of defective lots, or percent of lots that are partially defective.

This use of a "lot" as a unit to minimize the record keeping necessary, is another result of looking at a production area as a single system of causes turning out lots as units of work. Mr. Crawford uses a "lot" as a unit during inspection and then finds the percent of defective lots accepted. Knowing the distribution of defective lots with respect to the percent of defective pieces within the lots, and knowing the Probability of accepting the various lots, then the percent of defective lots accepted can be related to percent of defective parts in stores.

In other words, Mr. Crawford works with a partially defective lot as his basic unit. On the one side he relates this empirically to defective parts produced and on the other side he relates this with sound theory to defective parts in stores. Another thing apparent from the beginning is that Mr. Crawford is not concerned with minimizing the average amount of inspection necessary. This is because the alternative, as he sees it, is not a minimum inspection plan, but rather 100% inspection to minimize record keeping.

In closing I would like to point out that resubmitted lots constitute a risk for which there is little protection with any sampling plan. To be effective, a quality control or sampling program must be supported by four basic elements in addition to the statistical method.

1. An accurate measure of the condition of the material.
2. A reliable, quantitative record of inspection transactions.
3. An intelligent analysis of the record, and
4. Effective action when the analysis indicates the need for action.

With this support, the selection of a sampling plan is a choice, dependent upon the skill of the individual applying the plan, and the circumstances surrounding its use. I will not attempt to define when discovery sampling should, or should not be used, but if records are a problem or if you produce a large number of small lots you would do well to investigate the advantages of discovery sampling.

BUILDING RELIABILITY INTO COMPLEX EQUIPMENT THROUGH THE APPLICATION OF QUALITY CONTROL PROCEDURES

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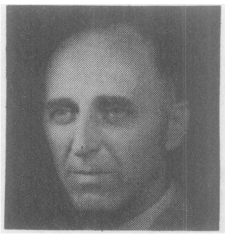


"What is Past is Prologue"

INTRODUCTION

The Purpose of Data

The above motto is engraved in stone on the face of the Archives Building in Washington. A story was told me by Dr. E. U. Condon of a Washington tourist who observed the inscription, and asked the taxi driver what it meant. After some hesitation, he replied with more perspicacity than he knew, "That means you ain't seen nothing yet."

We experiment, we test, and we take data primarily for one purpose, and that is to make predictions. The fact that we tested a sample of things of which a percentage failed is in the past, and is of no real interest except for:

1. The inference that we can draw about how the untested remainder will perform in the future, and
2. The changes that we can make in the things yet to be produced so as to reduce the percentage of failures.

Quality Control Procedures can do much to assist us in treating our tests and experiments as prologue to a more satisfactory future, rather than consigning the data with much of its vital content to the archives. Furthermore, if we can succeed in adapting to the large problem of reliability of complex equipment, the Quality Control Procedures that have done so much to improve the reliability of ordinary manufactured products, perhaps we "ain't seen nothing yet."

The Limitation of Scientific Acumen

However, the transmission from a product of a factory production line, to a complex assembly from many production lines (such as a guided missile) is not easy. We do not even know with satisfactory clarity how to organize for economically controlling the quality of such very complex assemblies as modern missiles. We in the military technical services find ourselves in the same dilemma as much of the rest of modern society in which men know in large part what the answers to many of their problems should be, but do not know the methods that should lead to the solutions of the problems. Briefly, and almost facetiously, we know the answers; it is the questions that we do not know. This anomaly is inherent in the scientific method which can be characterized as the orderly procedure from hypothesis to experiment, to judgment of hypothesis, and around the sequence again and again. In science, one proceeds from hypothesis to its proof (test) through a course of experimentations and concomitant analyses.

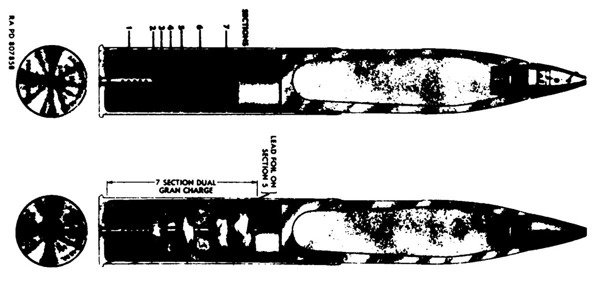
Hypotheses are generally in ample supply even though good ones may be largely dependent on genius or intuition, and the volume is attenuated in a practical way by the criterion that the solution to the problem at which they are aimed should be potentially feasible in the existing state of science and technology. Scientific progress is limited in marked degree by the analytical ability of the experimenter in devising means for the experimental verification of the possible alternative answers that have been postulated. Quality Control has contributed much to the realization that analytical acumen is keenly sharpened by prior organization of work into various types of experimental designs. With many groups of workers, design of experiment has become a part and parcel of the scientific method.

Since building reliability into complex systems seems analogous to and, in part, predicated on Quality Control, let us take a look at the parallel growth of Quality Controi and the growth of complexity of military equipment. Whereas, the major growth in complexity of equipment and the major growth of Quality Control was during and since World War II, both had their beginning earlier. The first Ordnance item to be fully subject to Statistical Quality Control was the simple artillery primer. This work was done at Picatinny Arsenal in the early 1930's, under my supervision, when I had the good fortune to live near Dr. Walter A. Shewhart, originator of Quality Control, and to receive his generous assistance. It was no spectacular achievement. It resulted merely in somewhat more reliable, more uniform artillery primers at lower cost. The system was soon expanded to many munitions components such as fuze parts and the explosive filler of artillery shell, but it was not until World War II that Quality Control was applied to a whole munitions assembly the small arms cartridge. Meanwhile, the Navy joined in this work and great contributions were made by American industry. The work paid great economic dividends in World War II, and the work of World War II, in turn, paid great dividends to the science of Quality Control.

The first step that was taken in establishment of many quality control procedures was analysis of the measurement process. In earlier times, the concept of variability of measurement, if understood, did not lead to very useful means of controlling results. Today, the variability in data is known to have a very important bearing on the confidence that can be placed in them. The accuracy and precision of measurements (dealing respectively with the general level and the scatter of the values) have come to have relatively well defined meanings. It is realized that the amount of testing that needs to be done depends on the variability to be expected when all the surrounding conditions have actually been constant. The questions of when, and where, and how much to sample and test can be answered explicitly by designing an experiment which will permit assessing the importance of all the known sources of variability. The concept of using inherent variability (the variability still present in a state of control) as the basis for determining when real changes in product or process have occurred has been extended to manufacturing chiefly through the use of control charts. However, it was not until the Korean War that this scientific discipline was extended to a whole ammunition system, the 105 mm. Howitzer ammunition.

Quality Control of 105 mm. Ammunition

A very large part of the colossal effort of a war is concentrated on the single end of delivering a lethal round of ammunition on the enemy. With the exception of the man behind the gun, the quality of no element in the chain of events - transportation, fire control, gun, etc. - is as important as the quality of ammunition. It is the ammunition that kills the enemy. Ordnance has never spared any effort and will never relax its vigilance to give the American soldier the best ammunition in the world and in the most liberal quantities. Let us look at the complex systems that must be brought under control, in order to establish Statistical Quality Control of the complete found (Figure 1).



COMPARISON OF SEMIFIXED ROUNDS FOR 105mm HOWITZERS

FIGURE 1

First, one thinks of the complete round assembly line, which is generally a plant covering hundreds of acres, into which flow from all parts of the country fuzes, boosters, empty projectiles from various metal parts manufacturers, high explosive for filling the shells, empty cartridge cases, smokeless powder, and other components. Suppose that one can establish quality control on each important operation of the complex assembly line; is that enough? By no means!

One soon discovers that to have real reliability, the control system must extend back to the maker of the empty shell so as to reliably control the tightness and quality of its copper rotating band, the size of the shell cavity, and the weight of the empty shell. Similar controls must tie in the work of the contractors for other parts, the work of their subcontractors, and sometimes must extend to sub-sub-contractors. Similarly, controls must be extended forward to the sampling, testing, and analysis procedures of the proving grounds. The Quality Control Procedures were devised and installed by the Quality Assurance Group of the Bell Telephone Laboratories under contract to the Industrial Division of the Ordnance Corps. This work could hardly have been possible at a very much earlier date because it required for its fruition the creation of new knowledge by the joint work of science, industry and government, the broad dissemination of this knowledge, and the training of many engineers in Quality Control.

Ammunition Was Never Before So Good

Let us glance at a few of the advantages and benefits of the work. The average lot of ammunition during World War II was between 3,000 to 4,000 rounds. The most recent lot of 105 mm. ammunition shipped to Korea was a single uniform lot of nearly 150,000 rounds. When one considers the fact that the artilleryman must fire trial fire to establish the calibration of each lot, one sees that the ammunition saving is enormous. However, what is far more important is the increased accuracy. The dispersion of this ammunition is a small fraction of the dispersion of the general run of ammunition that has existed heretofore, thereby insuring more hits on the target in less time, at the place and the time that they are needed. It is probably the most marked advance in ammunition that has occurred since the introduction of smokeless powder. At the same time, economies introduced along with the process not only pay for the new procedure, but it is also probable that the savings on this single lot offset all the money that Ordnance has spent on Quality Control since World War II.

Complexity of Guided Missiles

The transition from quality control of the primer to quality control of the complete round of ammunition seems great. However, the step from the complete round of ammunition to the guided missile is much greater. Let us consider the German V-2 Rocket, which really possessed only a programmed control rather than any real guidance.

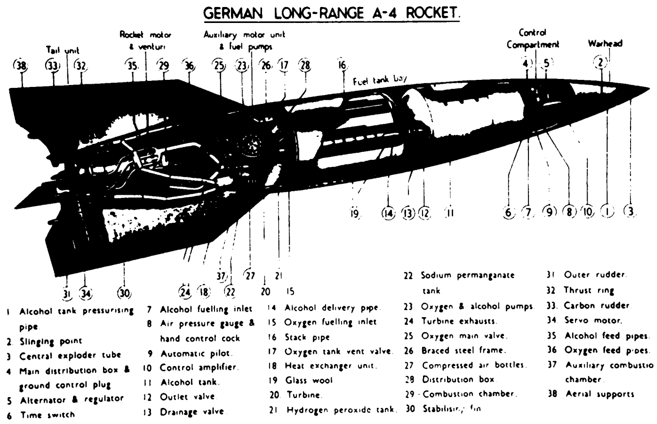


FIGURE 2

Meticulous as the Germans were about mechanical and engineering precision, about 25% of the V-2s failed on launching and about 25% more failed while enroute to the target. Their launchings were under relatively favorable climatic and interference conditions, and their missiles had not undergone any prolonged storage. A 50% failure in items as expensive as missiles is overwhelming.

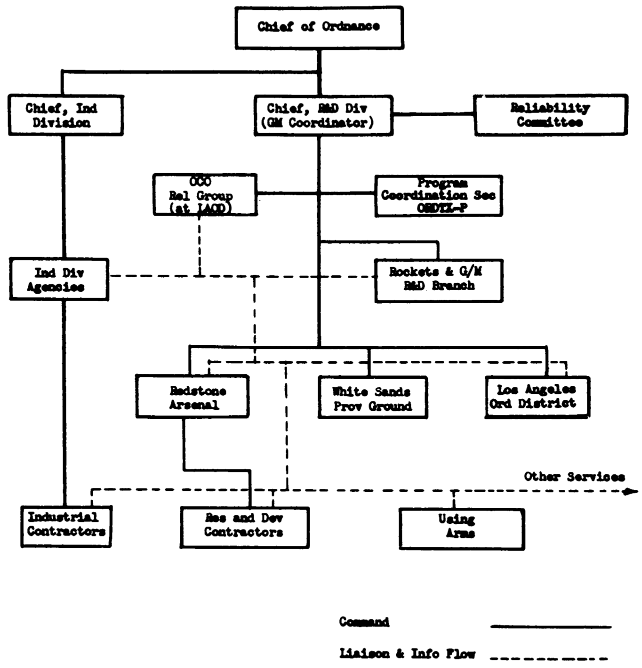
Modern guided missile systems are extremely complex in terms of the total number of parts in the structure as well as in the design of these many parts. This high degree of complexity increased the chances of failure. Let us consider a system of 100 components in series, each with a reliability of 99% (which is high for products of ordinary manufacture). The overall reliability, i. e., the probability that none will fail is obvious $(0.99)^{100}$ or 1/3. By way of further discouragement, guided missile systems are now, they are complex, and for these two reasons the conditions that they will experience in use are necessarily very imperfectly understood. Therefore, in this type of equipment we are compelled to work continuously on the frontier of existing knowledge in both science and technology. The tremendous efforts being expended on the general technical aspects of guided missile development increase rather than diminish the effort that is required to achieve and maintain reliability. The drastic shortening of the time that under normal circumstances would be available for development is in itself an element in this because it becomes necessary to initiate advanced stages of development prior to completion of previous stages: thus a mistake or change in an earlier stage which under normal circumstances would result in simple changes in development, now causes many changes in design drawings and production, all of which add greatly to the difficulty of achieving overall reliability.

However, all entries are not on the debit side of the ledger. Complexity of equipment is no absolute barrier to the achievement of reliability, if competent and conscientious men earnestly attack the problem. The Electronic Numerical Integrator and Computer (the ENIAC) is an extremely complex equipment that contains over 20,000 vacuum tubes, in addition to thousands of other components. When it was first delivered to the Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, it had a reliability of about 5%, in the sense that it could be made to operate satisfactorily only that percentage of total times. In a matter of weeks a small crew of engineers raised its reliability to 75% and it was subsequently raised higher. In fact, the compounding of variables, although confusing from the engineering viewpoint, is not necessarily unfavorable to Quality Control. Shewhart has shown that the approximation of the normal probability density distribution is enhanced by increasing the number of variables compounded. It is the dull subject of organizing for the task that is initially of principal concern; not the means; not even the probability of ultimate success.

Organizing for Attaining Reliability in Complex Equipment

Complex equipment, such as guided missile systems, offers a challenge to the quality control profession. It will require a higher degree of organization of all activities involving reliability of performance than has usually been considered necessary. As expensive as missiles are, every piece of valid data must be gathered and utilized from the inspection results of the production line to the target practice results acquired in the training of troops. We must know not only that a failure occurred; but, if practicable what part caused the failure, and why. We must then see to it that the cause system that produced the defective part is discovered and corrected; and, in serious cases, modify the unused items that were produced prior to the correction. Such a program calls for an organization within government, but it must be one which will influence even the subcontractors of contractors for component parts to install Quality Control. Such influence can be exerted at least through the medium of good acceptance inspecting such as that done during the war in accordance with the Ordnance Sampling Tables.

It is believed that the most expeditious and economical manner of promoting reliability of guided missiles under the present program is through a guided missile reliability organization which has the specific purpose of applying techniques for achieving reliability. Although the ultimate responsibility is shared by all who have a part in the missile program, the ad hoc organization should help to correlate all the efforts and to focus attention on the most critical aspects of any given time.



Ordnance Guided Missile Reliability Organization

FIGURE 3

The special problems of quality control, acceptance inspection, check-out before firing, feed-back of test results, measurement of environmental conditions, planning of component tests, and other problems are covered in the overall plans for a reliability organization which Ordnance has underway. The proposed organization, when completely effected, will consist of:

a. A Guided Missile Commodity Coordinator who coordinates all aspects of the guided missile program.
b. An Ordnance Guided Missile Reliability Committee with representation from all branches of Ordnance concerned with the problem, that advises the Commodity Coordinator on Reliability aspects of guided missiles.
c. A small permanent working group known as the Office of the Guided Missile Reliability Coordinator, that actually performs overall liaison and coordination.
d. An arsenal reliability committee to coordinate arsenal matters concerning design and procurement, feeding information from and to the permanent group.
e. A permanent reliability office at the missile proving ground to coordinate the engineering evaluation of the systems and similarly feed information.
f. The assignment of liaison and coordination responsibility in reliability matters for specific missiles to individuals or groups in each of the following: development agencies and subcontractors; production agencies and subcontractors; Ordnance inspection and test agencies; Ordnance maintenance and field agencies; and the using forces.

Each segment of this organization will have specific responsibilities for improving and maintaining the reliability of the product. It is to be noted that the organization is primarily one of liaison and information flow, with actual command remaining in the normal channels.

Flow of Reliability Test Data

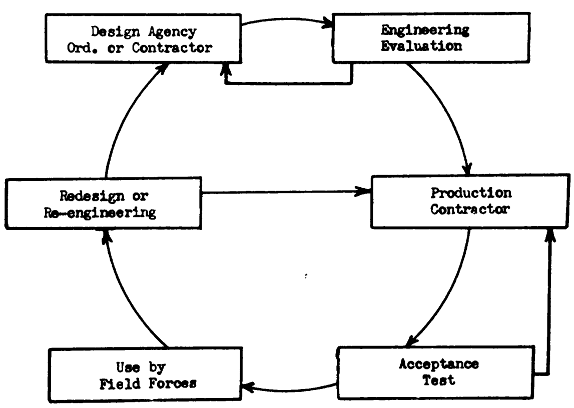


FIGURE 4

The Ordnance Guided Missile Reliability Committee will recommend the basic Ordnance policy on reliability organization. The Office of the Guided Missile Reliability Coordinator will coordinate the reliability effort for the entire Ordnance guided missile program. It will report directly to the Guided Missile Commodity Monitor in the Office of the Chief of Ordnance and will be competent to assist either government agencies or private contractors in developing their individual parts of the reliability program. It will accomplish its operations normally through recommendations, relying on the normal command function only if required.

Reliability groups are necessary at both the Ordnance arsenal and at the proving ground. The arsenal is primarily responsible for improvement in reliability; the proving ground for independent measurements and evaluation at any given stage of development. Thus, the proving ground is responsible for the determination of the reliability of an entire system or of major units. Also, it is responsible for determining the environmental conditions encountered during flight that must be used for realistic design and testing. The arsenal has the responsibility, retained or delegated, for the development of overall reliability and primary responsibility for measuring and developing the reliability of component parts and assemblies which can be tested adequately only during development or production. The arsenal is also responsible for review of the design criteria from appropriate reliability considerations. Both arsenal and proving ground are responsible for providing adequate and timely feed-back of reliability data to the appropriate agencies.

In current and future missile developments, it is essential to have a reliability review at the development contractor level. A study should be made of the characteristics of components prior to their becoming a part of the missile design, and their reliability should be evaluated against the known or assumed environmental conditions to be encountered during use.

The production agency's quality control department should be pressed into service as a reliability group, if the agency has quality control. To secure such cooperation, it will be necessary to convince the agency of the importance of component reliability to overall performance reliability. Where no quality control department exists, effective acceptance inspection programs must be enforced to maintain proper quality level. In either event, valid quality levels must be established and risk factors chosen only after careful evaluation of the penalties associated with the risks.

It is important to have the Ordnance inspection organization reliability-minded. A clear channel of communications for reliability matters must exist, and the government inspection organization is a very important element in this channel.

Each group or installation handling the missile or missile components must designate some of their personnel to be responsible for reliability matters. The collection of needed information will be expedited by a well-organized channel of communication on reliability matters.

Conclusions

This plan for a reliability organization is the most feasible that Ordnance can devise at the present time in terms of not creating delays and not upsetting normal command channels. Since it can undoubtedly be improved, comment and criticism are earnestly desired. We believe that the plan provides a channel for information not only within Ordnance, but also between Ordnance and the using arms, between Ordnance and the other services engaged in guided missile developments, and between Ordnance and the industrial contractors involved in design and in the production of missiles and their components. It also provides a channel for direct flow of information between each of the non-Ordnance agencies. The plan involves people who are competent in engineering, people who know how to design test programs, and people conversant with acceptance sampling plans and quality control procedures. Since the amount of complete systems testing that can be done is limited both by time and particularly by cost, unusual detailed attention must be given to adequacy of design and satisfactory control during manufacture for guided missiles.

The really basic approach consists of applying long established procedures for making the parts and assemblies as uniform and of as high a quality as possible. Quality must be assured long before the final and destructive flight test takes place. This means that many contractors and subcontractors not using statistical quality control to its fullest extent must be persuaded to do so.

Undoubtedly, some parts of the present plan will prove inadequate in the light of unforeseen aspects of the problem, requiring an innate flexibility of the plan to adjust to established conditions. However, papers such as those given at the Fourth Industrial Engineering Institute and such as those on the present agenda lend confidence that the ingenuity of American scientists and engineers is sufficient to the task. There has never been a time when science and industry has not given Ordnance every available support, and the same teamwork that has brought conventional ammunition to its present high state of perfection will also make certain that our new problem child, the guided missile, is at least acceptably reliable.

BUILDING RELIABILITY INTO COMPLEX EQUIPMENT THROUGH THE APPLICATION OF QUALITY CONTROL PROCEDURES - DISCUSSION

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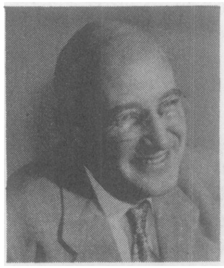


We have been greatly honored to have General Simon present this excellent paper in person, knowing the busy life he leads. It has been both instructive and inspirational. This message is particularly applicable to a large number of the industries in this Los Angeles area. So many are engaged in defense programs acting as contractors, sub-contractors and even sub-sub-contractors. Many are engaged in the manufacture of missiles or allied parts. It is absolutely necessary that those with Army contracts cooperate with him in the six-fold organization which he has outlined. Similar programs should be prepared and followed by contractors dealing with the other services.

Inasmuch as I may consider that I represent the contractor's point of view, I wish to discuss this paper and the effect of this program on the contractor. What is the contractor expected to do to render the most assistance. It is imperative to obtain good data and make the greatest possible use of these data. Scientific experiments must be carefully planned to check all possible hypotheses. Quality Control procedures must be applied. In order that many statistical techniques, such as analysis of variance, may be most efficient it is necessary to properly design the experiment. This is most important when dealing with extremely complex equipment.

The General brought out the point that it is relatively easy to maintain control over simple components. The problem is to properly integrate these controls so that the final complex system will function. These experimental controls provide evidence as to the magnitude of the tolerances that can be satisfied and also that can be complied with in production. The Engineer may have a very satisfactory design from his point of view. The manufacturer, however, finds it impossible to make the components in mass production. He suggests changes that literally wreck the original design, but by mutual effort a working design is obtained that is as good, if not better, than the original complicated design; and, most important, it can be produced rapidly and cheaply using mass production methods.

In making any product, it is essential that reliability be built in during all stages of manufacture. The production engineer plans his operations to that end. He needs help from the Quality Control group to determine whether he is achieving his goal. Manufacturing and Inspection must work in unity being tied together by modern quality control principles and methods. Rework is costly at all times. It is especially costly in the electronic field. A fair piece of equipment with a few minor discrepancies can readily become through rework an unsatisfactory piece of equipment containing major discrepancies. It is an engineering crime to have a fine piece of equipment torn to bits by a rework artist with a prying screw-driver, or worse yet by a prying Inspector, whether he represents the contractor or the purchaser. Since it is difficult to rework quality into a poor product, it must be built in. This requires In-Process controls of the highest order. Corrective action must be taken as early as possible.

Many Quality Control Systems have failed due to lack of proper communications. When data at any stage of production, inspection and test indicate a departure from standard operations, the information contained in such data must be fed back to those at fault as rapidly as possible. If this line of communication is poor, much waste results. Also the component is no longer a reliable component. Its range of variability is unknown. Consequently, the assembly of such components is questionable. They may cause more harm than good. It is better to hold such components until positive evidence is obtained showing that they can be used or that they should be replaced with new components. Needless scrap is a waste. However, it is often worse not to scrap defective pieces, since it requires only a very few nonconforming components to wreck an entire system made up of many of these components and parts.

Another cause of failure is the unthinking nonconsideration of quality requirements by expediters and production. It is true that a good production man feels he must keep his line running at all costs. If the line is stopped, it takes considerable time, effort and skill to start it flowing again on the same or a better basis. Valuable time is lost and productive effort is decreased. Also the quality of the outgoing product usually is poorer for some time until the line again becomes stabilized at a satisfactory quality level of production. The solution is not to push the product out the door regardless of its quality. When that is done, usually the product is returned and the problem is intensified. Teamwork with other groups, engineering, inspection and Quality Control prevents the building of poor quality products. The Quality Control group helps manufacturing by providing preventive measures to maintain both quality and also the production schedule. It provides the manufacturer with evidence of lack of control as quickly as possible. In this connection, it is often wise to set standards and control limits tighter than actually required so as to quickly stop any trend towards the production of unsatisfactory pieces. Many production groups use 20 control limits when management uses 30 control limits. This preventive program requires organization of the highest type. It requires the development and application of simple methods and the closest coordination between Quality Control and the Manufacturing group. Each has a part to play and their efforts must be synchronized. Team work is necessary. The mere taking of data, analyzing it, compiling it, and preparing fine reports, is not sufficient. Data are taken for a purpose. That purpose is to control the quality of the product at a satisfactory level. Other uses are supplementary. The lines of communication back to the source of the data must be as short as possible. Then it is possible to realize the goals set forth by General Simon.

In the manufacture of Missiles or other complex equipment, the General's paper indicates the necessity for maintaining extremely close controls over the various component parts. Over-all reliability must be achieved.

The contractor must make tremendous efforts to achieve these controls since even the design is not as firm as it should be. Time has been shortened to meet the missile schedule. Designs are not firmed. This results in development work being merged and intermingled with productive processes. Even under these conditions quality control and inspection must not take the place of the engineer. They are assistants, pointing out the weaknesses in design, casting out the discrepant pieces, assisting the engineer in his choice of tolerances, and effectively providing manufacturing with danger signals when production methods change or production shifts occur that may impair the final quality.

General Simon has pointed out the need for a missile reliability organization to apply proper techniques for securing reliability. He has outlined the contractor's part in this organization. The contractor can, however, go beyond this by providing the right kind of data that may be used immediately for securing the reliability desired by the government. Commercial manufacturers must provide this reliability due to the severe competition they meet. In this defense program the same factors apply, often to a much greater extent than in private business.

The best methods of inspection and test require some media together with instructions for their use to indicate what decisions must be rendered concerning conformance to engineering requirements. Blueprints are bulky and difficult to use on the line. A satisfactory substitute for them are complete check lists, giving all items for which inspection must be made at each inspection station. These lists are sometimes termed "What to Inspect For." In conjunction with them visual models are often used to assist in judging border conditions of acceptability.

Each characteristic should be recorded. Its seriousness should have already been determined by the engineer in charge of that design. Those items that are merely qualification or design items should be so designated by the engineer and not be listed on specifications the same as the key requirements. A program should be provided covering such items in detail for any fairly large-scale manufacturing operation. The gathering of such periodic data should be arranged on a definite schedule. Its use should be properly organized to attain maximum benefit from its analysis.

A demerit system should be introduced on either a three-fold or a four-fold basis. Some characteristics may have two classes of seriousness or even more, depending on the nature and degree or extent of the nonconformance and its effect on the circuitry and operation of the complex equipment. These demerit lists need not be too complex. They can be general and also explicit. Soldering, wiring, dressing, assembly and similar items may be covered for many different components in a general list. Thus the demerit list should consist of two parts, a general list and a specific list.

The classification of characteristics and defects is now being studied by many concerns and by government agencies. Many commercial concerns have had such plans in operation for as long as 20 years. When used in connection with other quality control techniques, the use of these techniques and methods should be of the greatest assistance in maintaining the quality of any product at a satisfactory level and with a sufficiently narrow distribution that it may be considered a reliable product. These controls are among the most important segments in the program outlined by General Simon.

JOB EVALUATION AND WAGE INCENTIVE SESSION

Session Chairmen: John R. Burton, Berkeley, January 31, 1953
Ralph M. Barnes, Los Angeles, February 2, 1953

Matthew A. Payne
National President
American Institute of Industrial Engineers

It's a privilege to be here with you attending the Fifth Annual Industrial Engineering Institute of the University of California. I'm very much impressed with the program, the speakers, the fine attendance and also, by the ideal facilities afforded the meeting by this beautiful campus.

Having left several inches of snow in Ohio to come, I'm doubly pleased to be here. It's hard for me to realize that you people have this clear sunny weather all the year around!

The American Institute of Industrial Engineers is proud that its San Francisco-Oakland Chapter is cooperating to produce this Institute and is specially proud of the work of its individual members who are presenting papers here or who occupy positions on the managing staff.

Conferences such as this are closely related to the very purpose of the A. I. I. E. The problems of the Industrial Engineer are not the type easily solved by one person working alone. They frequently are more problems of understanding, judgment or experience than of a number or a formula. This is because Industrial Engineering deals with people - - and people do not adapt easily to formulae.

While one man's fact or formulae may be as good as another's, or as good as that of a group of men, his understanding, experience and judgment may not be. There is thus a real need for forums such as this and, incidentally, for organizations such as the A. I. I. E. whose purpose is to cooperate with or provide such forums.

I believe deeply that Industrial Engineers who have the opportunity and who fail to attend and actively contribute to such conferences and who fail to support their professional organizations are out of step with the times and are seriously amiss in shouldering the responsibilities of their profession, and its service to society.

I'm honored to have these few moments of your valuable time. Again, I want to express my pleasure in being here and to extend to all of you the best wishes of the American Institute of Industrial Engineers for a most successful conference.

JOB EVALUATION

M. R. Lohmann
Professor of Industrial Engineering
Vice Dean
Oklahoma A. & M. College
Stillwater, Oklahoma

Job Evaluation is probably the most important technique used in a program of wage and salary administration because it aids managers to establish a structure of rates that is consistently related to the difficulty of the jobs. The establishment of a structure of job rates considered by employees to be fair and equitable is the first step as rating of the performance of an employee is meaningful only in terms of the duties assigned to him, which is his job. Some systematic procedure, preferably job evaluation, should be used to evaluate the difficulty of jobs and establish a rate or range of wages or salaries for each job before an appraisal is made of an employee by any systematic merit or performance rating procedure for the purpose of determining the particular rate within the rate range for the employee. Job Evaluation is a procedure to systematically measure the difficulty of duties performed without considering how well the duties are performed by the job incumbent.

Merit Rating is a systematic procedure to measure employee performance. These two techniques constitute, with other minor techniques and procedures, a program of wage and salary administration for any company.

Objective of Wage and Salary Administration:

The objective of a wage and salary administration program is to determine and pay wages and salaries in a manner most satisfactory to employees that will result in greater productivity in the future. Wages and salaries are a major part of the system of incentives that influence men to cooperate in organizations. Employees are rewarded on the basis of the work performed or service rendered today to provide an incentive for the maintenance of or increased productivity tomorrow. The problem of wage and salary administration is to so divide the available funds for wages and salaries among all employees so that all employees as a group will maintain or increase their productivity. Probably more important than the absolute amount of the wage is its relationship to wages paid other men in the company. A wage is high or low only when it is compared to other wages.

Administrators of wages and salaries, which includes all supervisors and managers as well as staff assistants usually in personnel or industrial relations departments, are concerned with two aspects of wages--the absolute amount and the relationship to other wages. The absolute amount determines the total payroll and is determined by many factors, among them are industry and area comparisons, bargaining power of unions, and ability to pay. The relationship of the wage to other wages is considered fair if it reflects agreed differences in either job difficulty or employee performance. It has been conclusively demonstrated that, to the employee, an equitable relationship is more important to his satisfaction than the absolute amount of the wage. This fact is sometimes obscured by the frequent demands of unions for higher wages and the publicity given to these demands. It would probably be more accurate to say that the absolute amount of the wage may be a cause of the employee's unsatisfaction and the relationship a cause of dissatisfaction. The unsatisfied employee may be cooperative and productive, the dissatisfied employee seldom is.

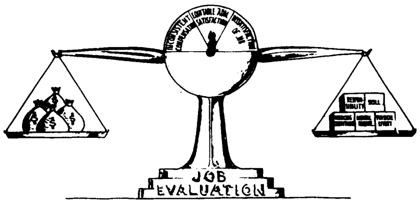
Employees are the Judges:

The determination of whether a particular wage is fair and equitable is always made by the employee, for the wage is intended to favorably influence him. If the employee believes that a wage is not fair and equitable, the value of the wage as an incentive is decreased and the employee withholds his cooperation in whole or in part. "Soldiering," loafing, and strikes are evidence of the failure, as measured by the employee, to offer adequate incentives.

Of course, it is recognized that it is impossible to devise a system of wage payments that will be entirely satisfactory to all employees. For example, the wage differential that may stimulate the man with the higher wage, may discourage the man with the lower wage. The objective of the wage and salary administration program is to satisfy to the highest degree possible the majority of the employees. Knowing that probably no one will be perfectly satisfied, at least the degree of dissatisfaction can be equitably distributed. The final objective desired is always greater productivity tomorrow and the means to this is capable employees willing to work and cooperate.

Systematic for Consistency:

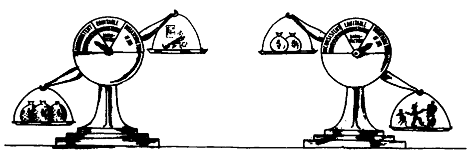
The manner, most satisfactory to all employees, of determining compensation is by the employment of a systematic technique to achieve consistent results.



COMPENSATION & JOB CONTENT *in* BALANCE!

Consistency is the key to any successful wage and salary administration program. Given the same facts, the answer should always be the same. Given the same job duties, whether performed in the sales office or production office, the salary range should be the same. Both organized and unorganized labor have tended to prefer seniority rather than merit rating as a means of measuring men for promotions in either jobs or pay because it is so systematic that it always achieves perfectly consistent results.

Accuracy has no meaning in wage and salary determination because there are no absolute standards. A wage is more or less satisfactory, dependent upon internal consistency, acceptable relationships between jobs within an organization, and external consistency, acceptable relationships between organizations or between an organization and outside factors such as the cost of living.



Unsystematic METHODS *RESULT* *in* INEQUITABLE *Wage Administration*!

No system of job evaluation can be judged on the basis of accuracy, but any system can be judged on how consistently it measures the difficulty of the jobs in a company. Job evaluation is a most valuable and important technique of wage and salary administration because it is systematic and if properly used it does achieve consistent results.

Job Evaluation Defined:

Job evaluation is a systematic technique to aid competent men in pooling their judgments to solve problems of compensation in a consistent manner. Jobs have always been evaluated and differential rates of payment established. Various methods have been employed including overall informal appraisals by supervisors, job ranking systems, and job classification systems.

"JOB EVALUATION" *is a* DEFENSIBLE METHOD *of* DETERMINING *the* INTERNAL ALIGNMENT *of* JOBS!

Job evaluation is justified and should only be used if it is more consistent in measuring job difficulty than the method presently used and the job rate structure is more satisfactory to the employees influencing them to be more productive. It is not a science, only a method or a procedure designed to improve the consistency of the determination of job difficulty and the establishment of an agreeable structure of job rates. If your problem is anything but inconsistent rate relationships, pay that is not consistent with job difficulty, then job evaluation will not solve your problem.

Judgment:

The evaluation of any quality requires the use of judgment and this is true of the evaluation of jobs. The consistency of judgment may be improved by the employment of a systematic procedure involving a series of familiar appraisals. For example, most of us could not directly estimate the volume of a room within plus or minus fifty per cent, but if we were asked to judge first the length of the room, the width of the room, the height, and then multiply these estimates, we would probably be within plus or minus ten per cent of the correct volume. In addition, the estimates of length, width, and height would be more accurate if men, competent by reason of their education and training, shared their experience and knowledge. The individual and thus the pooled judgment would be improved.

Job Evaluation does not correct past mistakes, it only identifies them and measures their extent. It does provide useful information that can prevent a repetition of the errors of judgment. Job Evaluation can to this extent be compared to cost accounting, for cost accounting doesn't lower costs or correct wasteful practices, it only points out high and low cost practices or procedures and thus aids managers in avoiding the repetition of costly practices. Like cost accounting, job evaluation is basically a technique of measurement, the measurement of job difficulty.

When Is a Job Rate Out of Line:

A salary is neither high or low until it is compared to other salaries on the basis of some factors or qualities. A wage is "out-of-line" only when compared to some wages that are "in-line." If a company of soldiers were marching down the street and one had started with his right foot instead of his left, his Mother standing at the curb might say, "Look, everyone is out of step but my Johnny." But the company of soldiers would say, "Johnny is out of step." In very much the same way, there is a relationship between job difficulty and job pay that is considered by employees to be "in-step" and equitable and jobs considered by them to be inconsistent or 'out-of-step' are those that do not conform to this relationship.

It is the function of a job evaluation system to discover the factors and their individual importance of this generally agreeable system of relationships between jobs and pay, and to establish a consistent procedure for considering these factors and their importance for all jobs. It is not the function of job evaluation to create an entirely new system of rate relationships for this would, in all probability, be unacceptable to the majority of the employees. There is no scientific reason why one job should pay more or less than another job, there is only traditional rate relationships established by values socially determined and this traditional rate relationship has, through usage, come to be considered fair and equitable by both labor and management. To further complicate the problem is the slow but steady change in our system of values that changes the rate relationships. This has been especially evident in the changes in the past twenty years in the rate relationships between unskilled and skilled labor or between clerical and manual labor.

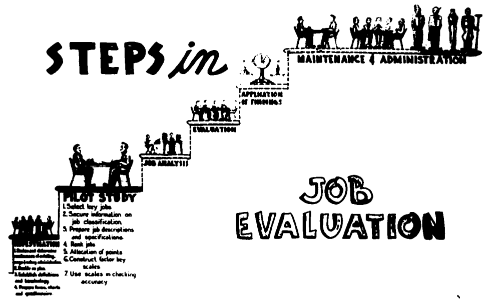
Plans Must be Designed for Each Company or Industry:

The most acceptable and thus successful job evaluation plan is the one that considers and is built from the overall traditional wage structure in the particular company or industry. The concept of job difficulty is by no means consistent between industries and frequently inconsistent between companies in the same industry. The relative weight that should be given to the same degree of hazard or physical effort when determining job difficulty is not a constant between organizations and should not necessarily be a constant. In a free market economy, price is a rationer of goods and wages a rationer of jobs. Unfortunately, many companies, particularly smaller organizations, have borrowed a point plan of job evaluation and installed it in their organization with unsatisfactory results. Although one would seldom, if ever, borrow someone's accounting procedures including all the forms, depreciation schedules, overhead rates, and other details and install in his plant without modification to suit conditions peculiar to the plant, yet this is frequently done with job evaluation systems. The basic structure may be borrowed but modification is always necessary.

Development and Application:

With an understanding of these concepts as a background, it is now possible to comment more specifically on the development and application of job evaluation systems. In this brief statement it is not possible to discuss in detail any particular job evaluation plan. It is hoped to create a general understanding so that those who are interested in the detailed techniques may have a body of concepts useful to understanding the numerous books on job evaluation.

Job Evaluation is a technique to price jobs and not fundamentally different to our method of pricing products in a free market, competitive economy. Jobs are priced on the basis of their characteristics or factors just as a combination of various qualities of an automobile determines its price. The desired end result of job evaluation is a scale of wages that is satisfactory to employees influencing them



to work; the end result of pricing products is a scale of prices that is satisfactory to customers influencing them to buy. Although like any analogy, this one is strained in several places, yet it may be useful to understanding the theory and practice of job evaluation systems.

Descriptions are Essential:

Before jobs or products can be compared, a written description of their essential features is necessary. For products, we generally call this description a specification and while the term job description is most common, the term job specification is sometimes used.

The jobs must be described in a manner so that they can be compared. This means accurate, comprehensive, and complete descriptions of the duties of each job. As it is not possible to bring the job to be compared to a central place, the description is used for comparative purposes. It is written by job analysts from information gathered from questionnaires and interviews of the job incumbent and the immediate supervisor.

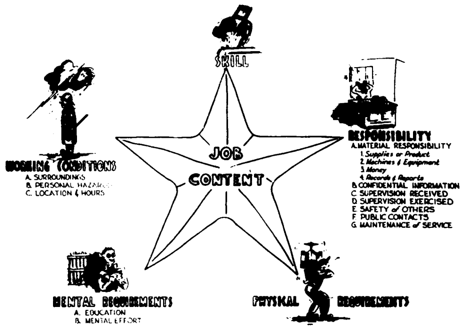
To facilitate comparison, judgments of the various human qualities necessary to perform the duties of the job are recorded.

Job Difficulty and Quality of Products:

Jobs like products cannot be directly compared. The quality of a product is not something that can be abstracted and compared except in terms of elements such as weight, strength, length, design, color, and many others. If two chairs were to be compared to determine the price that each might command on the market, it would first be necessary to enumerate the elements of the chair that together are considered to comprise quality. The elements must be those things that customers deem valuable and must differentiate one chair from another. Some of these elements might be strength, weight, amount and kind of padding, and proportion. The product specification must emphasize these elements for chairs are compared by elements. Note that all elements are not enumerated because either the customer places little or no value on them or they do not differentiate. If both chairs have four legs, there is little reason to describe and compare this feature as the result will be equal for this element.

In much the same way, the job factors are selected as the basis for comparison of jobs. The total of the factors comprise the difficulty of the job. The terms job difficulty and difficulty points are similar to the words value of quality and price as they pertain to products. Job difficulty is the sum of the factors and the difficulty points is a numerical means of expressing job difficulty and is the sum of the value of each job factor.

The job factors should pertain to all jobs, be considered valuable by employees and differentiate the jobs. There are four main factors that are used in all job evaluation plans: effort, responsibility, skill, and working conditions. In addition to these main factors, there are many sub-factors such as: education, previous training, accuracy, mental effort, physical effort, monotony, responsibility for material, equipment, safety, money, accident hazards, and health hazards.



Professor Lawshe of Purdue has found that practically all variance in job difficulty can be measured using only three factors but most plans in use have from five to ten factors. A large number of factors does not increase consistency of evaluation and may greatly add to the complexity of the plan.

Evaluation of Jobs - Pricing of Products:

The range of value for any job factor is from some minimum amount to some maximum amount with all jobs having some degree of this factor between and including the minimum and maximum amount. The maximum and minimum value of any factor is usually different from other factors. That is, the maximum points allowed for effort is generally not as high as the maximum for skill, while the minimum for effort is lower than the minimum for skill. This variation in value is also true for elements of quality of products. Customers may value proportion more than they do strength. The exact value placed on each element of quality by a customer is not necessarily a logical and precise process, but the result is obvious--he either pays the price or buys an alternative product that he considers to be a better bargain.

In chairs, the relative value of strength, weight, padding, and proportion is not determined by the manufacturer or seller, but by the buyer or customer. In the long run, it is the customer not the seller that determines the price. It is true, of course, that the seller initially establishes a price for chairs, but if in the judgment of the customers the price is out of line with other chairs of comparable quality, the chairs won't sell until either the quality is increased or the price lowered. Thus, it is the combined judgment of many consumers that determines the relative weight of the elements of quality. The process is unsystematic and probably something like the example that follows: The customer attempts to determine the degree of each element of quality possessed by the two different chairs. One chair may be stronger but heavier, with more padding, but poorly proportioned. The customer then attempts to weigh the different degrees of each factor to arrive at some total or sum, which is the total quality to which he compares price. For example, he tries to determine if the extra strength is off-set by the greater weight or whether the value of the padding is off-set by the loss in proportion. The chair he purchases will be the one which in his evaluation has the most quality per dollar of price.

The evaluation of jobs is essentially a similar process but more systematic for greater consistency. There is no scientific method of determining the relative value of effort as compared to skill. There is also no scientific method of determining the relative value of different degrees of skill. The only values that are pertinent to this problem are the customers of jobs, the employees, for it is they who judge the salary and determine if it is fair and equitable.

All job evaluation plans determine the relative value of the degrees of the factors by either breaking down by ranking and rating some key or bench-mark jobs (factor comparison system) or by testing empirically determined values on a group of bench-mark jobs (point system).

The principal criteria in the selection of these bench-mark jobs is that the relative wage or salary currently paid should be considered by employees to be fair and equitable. The employees may be unsatisfied about the absolute amount, but should not be dissatisfied with the relationships of the wage rate of one bench-mark job to another.

The system of weighing the degrees of the factors is satisfactory when, after the bench-mark jobs are evaluated and the total difficulty points determined, the points made by plotting the difficulty points against the present salary or wage of the jobs is in some continuous line, either straight or curved. The detailed process of determining the weights for the factors is too lengthy for description here. It is important to note that the value or the number of difficulty points assigned to any degree of any factor is determined from jobs whose relative pay is already satisfactory. The expectation is, of course, that other jobs measured by the same system of values of the factors that were satisfactory for the bench-mark jobs will be equally as satisfactory for all other jobs. The pay for any job is aligned to the pay of the bench-mark jobs by a systematic appraisal of the degree of each factor.

Factor or Point Systems:

The method of determining the degree of each factor may be by direct comparison of job against job such as comparing physical effort of a machinist's job to his helper's job. This is the method used exclusively by the factor comparison system of job evaluation. The degree of each factor may also be determined by comparing the job to some definitions of degrees of the factor. The physical effort of the machinist's job may be determined by comparing it to degree definitions such as "Lifting weights up to 40 pounds" and assigning the degrees whose definitions most closely approximates the quantity or quality of the factor in the job.

Grading and Rate Ranges:

Usually, a separate and different price is not established for every small difference in quality of product but only for significant changes in quality. The manufacturer who produces chairs does not establish a price differing by only a few cents for the chairs he paints blue although blue paint may cost a few cents more than white. The customer, whom the manufacturer wants to keep satisfied, may be unable to recognize this small difference in quality and thus may feel a price differential is unjust.

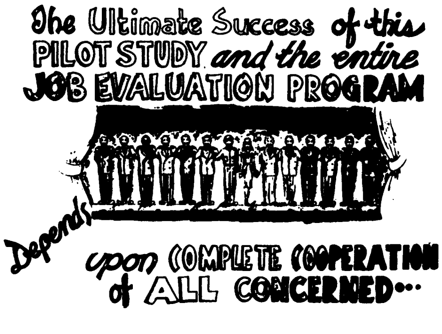
For the same reason - keeping the job customer happy - jobs varying only slightly from each other in difficulty are grouped in a single grade or class and a single rate or a rate range is established for all jobs in the class. The range of variation in the difficulty of jobs for inclusion in the same grade or class determines the number of grades. If the range of variation in job difficulty for a job grade is small, the number of grades will be large and conversely if the variation is large, the number of grades will be small and consequently, the number of rates or rate ranges will be small. The permissable range of variation lies between an upper limit of that which can be consistently detected by employees without a systematic procedure and a lower limit of what can be consistently measured by a systematic job evaluation procedure. The range generally used in practice is closer to the lower rather than the upper limit thus tending toward more job grades and rate ranges. The variation in overall job difficulty that can be consistently detected by employees without a systematic procedure is about twenty per cent, while the variation that can be consistently detected with a job evaluation system is about ten per cent. Or to state it differently, if the range of pay from the lowest job to be evaluated to the highest is three to one or three hundred per cent, then the number of job classes or grades would be from six to twelve,[1] with the most likely number about ten. For a range of pay of 400 per cent, the number of grades might vary from eight to fifteen with thirteen the most likely. The variation between the successive job rates or the mid-point of the salary range for job grades would be about twelve per cent.

If individual performance or seniority on the same job is going to be recognized by increased pay, then it is necessary to have a range of salaries for each job grade. Generally, for hourly rated factory jobs, there is only a single job rate, while for salaried office jobs there is a salary range. The difference between the minimum of the range and the maximum represents the difference in value of the performance of a qualified beginner on the particular job and the value of the performance of an incumbent that is superior. The mid-point salary between the minimum and maximum is for average performance. The extent of the range varies in practice from about twenty per cent to about fifty per cent with an average of about thirty-three per cent. Some consider it good practice to have a somewhat smaller salary range for the less difficult clerical jobs and a somewhat greater range for the more difficult technical and supervisory jobs.

1. This is determined by solving $3.00 = (1+i)^n$ for n when i is the per cent variation and n is the number of job classes. A simpler method is to use a compound interest table and note the n when the compound amount factor is three for the percent considered.

Summary:

A job evaluation system will be successful only if it is properly installed and adequately maintained. For most organizations, the payroll represents about one third to one half of the total costs.



It would seem to be only prudent management to so divide that payroll in a manner most satisfactory to all employees so that it will result in the greatest productivity. Obviously, the cost of employing systematic techniques to obtain consistent results must be less than the savings gained from an increase in productivity.

Initially, it will cost about ten dollars per employee, depending on the size of the organization, the number of jobs and the complexity of the jobs, to properly install a good job evaluation system. The annual cost of maintaining the system, such as keeping the job descriptions current, making necessary market surveys and doing the necessary clerical work, will be about one third of one per cent of the payroll. Thus, the gain in productivity must exceed about one third of one per cent to return cost of the system. A grain in productivity that small is impossible to measure but apparently thousands of companies believe that the technique of job evaluation does increase employee satisfaction and productivity for job evaluation is widely used in both the small and the large companies in all segments of American business and industry.

INCENTIVES FOR INDIRECT LABOR

George H. Gustat
Superintendent of Industrial Engineering
Eastman Kodak Company
Rochester, New York

Ladies and gentlemen, it is a pleasure to come before you and tell you something about the Industrial Engineering work that we are doing at the Kodak Park Works of the Eastman Kodak Company.

The idea of measuring indirect work is not new to industry generally or to my company specifically.

Most companies that embark on an incentive program usually start on direct repetitive work, but find before they get too far that they are forced into also considering a like program for their indirect workers. There are several reasons for this: first, as the direct costs reduce, the comparison between direct and indirect costs get more pointed, which in turn accelerates consideration of measures; and second, the disparity in pay between the measured direct workers and unmeasured indirect workers is hard to live with.

Theories on how indirect work ought to be measured are more numerous than I would have time to get into and there has been literally tons of material written on the subject. A talk on the theory of measurement would be a lot more fun and easier to prepare because one would only be limited by his imagination. How useful or informative it might be is open to question.

Professor Barnes, who asked me to come out here this morning, was much too smart to get caught in that one. He asked that I describe specifically how we do the job of measuring some of our indirect work, which puts me in the position of the doctor taking his own medicine.

Some information about our plant will help to give you an idea of the type of effort that we are involved in and will act as a base for the rest of this discussion.

The Kodak Park Works covers approximately 400 acres, 100 major buildings, and has approximately 20,000 employees. It is engaged in the manufacture of photographic film, papers and chemicals. It is an integrated industry, however, and manufactures most of its own supplies, e.g., it has its own paper box department, printing department, sundries department, where metal and plastic reels, metal containers of all kinds, film pack cases and many other supplies are manufactured.

Indirect incentives were started in our company by an outside consulting firm in 1922. The history of that coverage followed the usual pattern of such installations. It covered only the finishing departments where units of measure were easily found and where job analysis was relatively simple. The indirect labor in those departments was covered by a ratio of indirect to direct. It was not long until considerable qualification of the system was necessary to make it work and direct measure for the indirect gradually replaced the insensitive original ratio systems.

It was not until many years later that complete indirect service departments such as the shipping, laundry, maintenance shops, etc., were covered by incentive plans using direct units of measure.

Approximately 60% of all of our hourly paid people are on incentive, and approximately 83% of all people in the departments where we have incentives are measured.

Approximately 78% of the measured people are what we consider as direct workers who are engaged in a manufacturing process or operation dealing with either a raw or a partially-finished material that eventually gets into products that we will sell.

The other 22% are what we consider indirect workers who are performing a service function such as testing, handling, cleaning, shipping or an out-and-out service operation such as a dining hall, a shipping department or a maintenance shop.

We are using a standard-hour plan in which units-of-time measure are expressed in hours or fractional hours.

The time values are times to meet, and the effectiveness index for these items is 100%. To peg this level a little better, these times are equal to the 80 "B" hour in the old Bedaux system. They are times that we expect qualified incentive operators to meet and hold without undue fatigue.

This level of performance will yield approximately 20% of premium to the operators above the hourly rate of the job worked on.

I am going to describe three areas of our indirect work to which we have applied this kind of a plan.

I have selected these three examples because in each there is a departure from the conventional time study approach. The incentive coverage of indirect work at best is difficult and units of measure are hard to find. These are reasons why more work of this kind has not been covered, but if the engineer is ingenious, a practical solution can be found and the returns are as great as those from direct labor.

1. Warehouse handling group
2. Wood pattern shop
3. Cafeteria

1. Warehouse handling group

This was a group of 30 people in one of our film warehouses who were engaged in:

A. Receiving materials
B. Sorting and Stacking
C. Filling orders
D. Packing
E. Shipping
F. Reoperating (opening and repacking for tests, etc.
G. Record keeping

This problem could have been worked out with the conventional time study approach by having time study engineers make all-day studies of the duties of each person in the group. It would have been a costly and lengthy process.

We chose to use instead a combination of a ratio-delay and a statistical sampling approach which in this case required the time of only one engineer for approximately three weeks. This figure indicates why we used this approach and the advantages we hoped to gain from it.

Figure 1 & 2
Ratio & Delay

What is Ratio-Delay?

A method of evaluating an operation by

1) Making frequent observations of the elements of that operation, and
2) Determining the ratio of the elemental observations to the total number of observations, and
3) Expressing this ratio in terms of time.

Why Use Ratio-Delay?

1) Gets the facts at a fraction of the cost of time study.
2) More effective than continuous observation on a man-to-man basis.
3) Produces details and facts otherwise unobtainable.
4) Provides extreme accuracy where desired.
5) Enables engineer to study men, machines, equipment, method, and organizational set-up simultaneously.

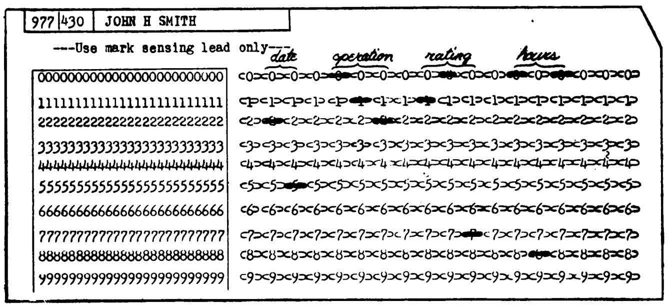
The engineer's first job, of course, was to spend approximately one week observing the jobs, selecting units of measures and determining work elements.

The units of measures selected were:

Footage of product received
Footage of product shipped
Number of reoperations

All of the work was broken into approximately 30 elements and coded by numbers so that on subsequent observations the engineer could note on an I. B. M. mark-sensing card whenever the element occurred.

Figure 3
I. B. M. Card Operations list



1. One card for each operator with operations encoded on card.
2. One set of cards for each circuit, cards checked with mark-sensing pencil

LIST OF OPERATIONS CODED ON CARDS

1. Check in film cases	18. Move cases
2. Stack film cases	19. Load cases
3. Lay-out cases	20. Date stamp
4. Pack film	21. Load dragline
5. Make out packing list	22. Inventory film
6. Transport to shippers	23. Receive instructions
7. Sort out odds and shorts	24. Put equipment on charge
8. Stack odds	25. Wait for fork truck
9. Get out re-operations	26. Wait for electric lift
10. Make up small orders	27. Wait for hand lift
11. Make out orders	28. Medical
12. Pack shipments	29. Late start or early quit
13. Pack parcel post	30. Personal time
14. Nail cases	31. Idle time
15. Stencil cases	32. Talk
16. Mark cases	33. Lunch
17. Wire cases	34. Out of department

(We think the use of I. B. M. cards here is a unique application of this tool.)

These cards, as you can see from this figure, show the operator's name and number, the check mark for the element observed and the rating or levelling factor on the effort observed.

In order to determine how many observations would be necessary to insure a ±5% accuracy on our operation times, we used this formula:

Figure 4
Statistical Equations

$$N = \frac{4(1-P)}{y^2 P}$$

Where N = Number of observations required
P = Estimated percent occurrence of any chosen operation to total time (i. e., men spend P% of time on this operation)
y = Individual operation tolerance (i. e., ±y% of P)

Solving this equation for our purposes:

$$N = \frac{4(1-.30)}{(.05)^2 (.30)}$$

N = 3730 observations

Actually, to aid in convincing supervision of our accuracy, we made well over 4,000 observations.

Mark-sensing I. B. M. cards were preprinted for each employee and each piece of equipment used. The engineer then circulated through the work places and observed each employee. As he came abreast of each man he would check mark the element of work performed and his rating of the performance. He rated each worker two or more times per day. The equipment cards were marked simply as to whether the equipment was in use or not. The list of operations on these cards covered all the work elements as well as idle time, instruction time, personal time, waiting for equipment, etc.

After the indicated number of observations were made, the cards were run through the automatic punches and then a summary report was run on the tabulator.

This report gave the number of operations worked on by each man and in total. To convert these totals into time values, the percent of each operation's occurrence to the total observations for each man was determined and then this same percent of the hours the man had worked gave us the time that he had spent on each operation. This time was then levelled using the average ratings obtained from the study. These levelled times for each element were added together for the whole group to arrive at the total time for each operation. This time divided by the production gave us the standard time value.

Figure 5
Comparison of Studies

COMPARISON OF STUDIES

Operation	1st Study - 4 days No.Obs.	% of Total	2nd Study - 10 days No.Obs.	% of Total
Receiving	257	13	655	14
Packing	689	36	1534	33
Sort and Stack	97	5	264	6
Small Orders	176	9	286	6
Shipping	345	18	796	17
Reoperate	112	6	101	2
Inventory	49	3	197	4
Wait for Equipment	42	2	152	3
Personal and Lost time	165	9	684	14
	1948	100%	4674	100%
Labor Hours	465		1236	

An interesting comparison was made between a preliminary study of 1,948 observations and the final study of 4,674 observations.

Notice the consistency of the percentage of occurrences in both studies. Our supervision was a little skeptical at first of this approach but are now completely sold.

This figure presents the type of control that is given to supervision to help administer this plan.

Figure 6
L.C.A. and
Posting Sheet

LABOR COST ANALYSIS REPORT AND POSTING SHEET

Labor Analysis Report

Warehousing - R. Smith
Dept. 977 - Bldg. 205

W/E wk. of ______ period

Code	Operation	Actual Hours: Time Work	Actual Hours: Incentive	Std. Hrs. on Incentive	% Effectiveness
26	Sundries Warehouse	16	150	157	105
27	Cine Warehouse		630	694	110
29	Chemical Warehouse		280		

Premium Posting Sheet
Weekly

Dept. 977 - Warehousing   Week Ending ______

Reg.No.	Name	Act.Hrs	Std.Hrs	%	Act.Hrs	Std.Hrs	%
977415	Rochard C. Roe	40	43	107			
977417	John W. Doe	40	44	110			
977418	Fred R. Smith	32	35	110	8	9	112
977420	Geo. T. Black	40	41	102			
977425	Chas. S. White	44	47	105			

The posting sheet indicates the operation each person has worked on and their percent of effectiveness. The Labor Cost Analysis Report is a summary by operations.

From these sheets the operator can calculate his own pay, and supervision has an index of effectiveness for each operation.

This figure presents what was accomplished on this job.

Figure 7
Before & After

RESULTS OF STUDY

Number of men required to do job:

30 vs. 16

11111 11111 11111   11111 11111 11111
11111 11111 11111   1

Amount of equipment required:

3 vs. 5

Actual Savings:
(Savings of 14 men minus cost of Equipment)
$45,000. per year

2. Wood Pattern Shop

Incentive measurement in a pattern shop is a little unusual and we believe that ours is unusually so because of the unit of measure that we use.

Here we have made use of a visual aid in setting up the units of measure.

As you know, a pattern maker must think in reverse of the materials that he must work with.

Usually his order for a pattern starts with a mechanical drawing of the part to be manufactured. Then, either the pattern maker, or the foreman, has to sketch the pattern (which is the reverse of the part in the drawing) and the necessary core box or boxes that will be necessary.

From these sketches, using woodworking machinery and tools, the Pattern Maker constructs the necessary parts and assembles them.

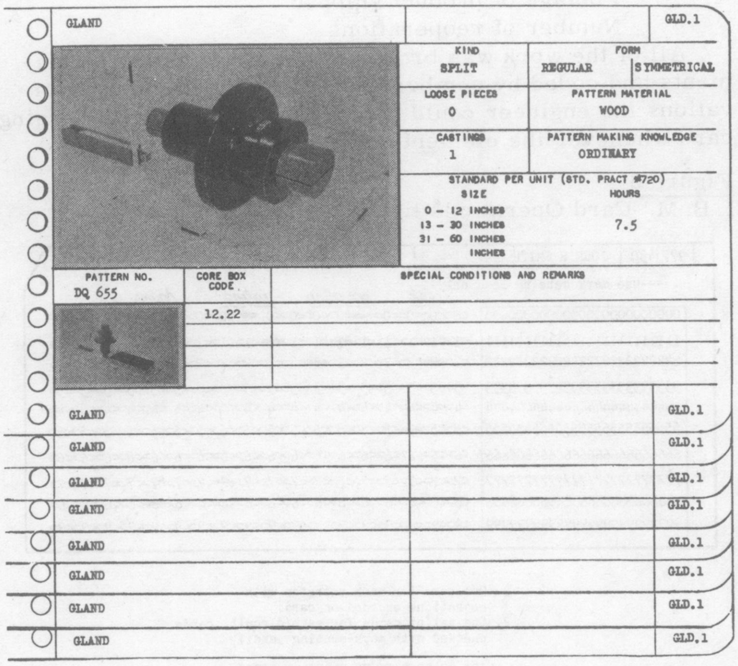
The approach that was made to this was similar to that described for the Warehouse group in that a ratio-delay and statistical analysis were used.

A great many observations were made and the total time used was levelled to arrive at standard times.

This job of measurement required about six months of an engineer's time. The foreman of the pattern shop and the engineer worked together and spent a good share of the time classifying the patterns that we had been making into different types. The foreman furnished the know-how from a standpoint of the shop and foundry requirement and the engineer the know-how of the technique of measuring. The job of classification to different types was also done for core boxes.

This next figure shows how the patterns were classified by part names and assigned a code number which enabled us to arrange them in a catalog for quick reference.

Figure 8. Alphabetical classification of patterns



ALPHABETICAL INDEX

PATTERNS

Part Name	Code	Part Name	Code
ADJUSTING DEVICES		GEARS	
Adjusting Plates	ADJ.1	Gear Blank	GER.1
Adjusting Blocks	ADJ.2	Cast Teeth	GER.2
Guide Bars & Ways	ADJ.3	GLAND	GLD.1
BASE		HOUSING	HSG.1
Plate	BSE.1	LEVER	
Block	BSE.2	Single	LVR.1
BEARING		Yoke	LVR.2
Half	BRG.1	MISCELLANEOUS	
Full	BRG.2	Cylindrical	MSC.1
BRACKET		Rectangular	MSC.2
Arm	BKT.1	NUT	NUT.1
Yoke	BKT.2	PAN	PAN.1
Angle	BKT.3	PISTON	PSN.1
BUSHING		PLATE	
Plain	BSH.1	Angle	PLT.1
Shouldered	BSH.2	End	PLT.2
CAM	CAM.1	Side	PLT.3
CAP		PUNCH & DIE	
Bearing	CAP.1	Punch	P&D.1
End	CAP.2	Die	P&D.2
CARRIAGE	CRG.1	QUADRANT	QUA.1
CONES	CON.1	RINGS	RNG.1
COUNTERWEIGHTS		SHELF	SLF.1
Rectangular	CWT.1	TABLE	TBL.1
Round	CWT.2	WHEEL	
COUPLING	CPL.1	Disc	WHL.1
DISC	DSC.1	Spoke	WHL.2
DISH	DSH.1		
FOLLOW BOARD	FBD.1		
FRAME	FRM.1		

As you can see, the patterns were broken down into approximately 30 different classifications by part names. The name of the part acts as the catalog code and any subdivision is numbered.

In addition there was a breakdown of the characteristics of the pattern's construction which aided in subsequent classification of any new pattern made.

As you can see from this figure, all of this information is posted to a 5" x 8" pattern data card along with the photograph. These characteristics of construction are:

Kind

A. Single-Pattern is made as a one-piece unit.
B. Split-Pattern is made in two parts, one of which is the cope, the other the drag.

Form

A. Regular - Pattern has even flowing surfaces.
B. Irregular - Pattern is broken up by projections or indentations.
C. Symetrical - Pattern is equally proportional around a central plane.
D. Unsymetrical - Pattern is differently proportioned on opposite sides of a central plane.

Loose pieces

A boss or pad seated (not permanently fixed) on the pattern in such a way that the pattern can be drawn from the mold without disturbing the loose piece. The loose piece can then be picked from the mold separately.

Pattern Material

Pattern is made of wood, metal or plaster

Castings Number of parts to be cast.

Pattern-making knowledge

A. Ordinary - Operator understands general patternmaking. Patterns may be somewhat irregular in shape, may or may not be symetrical. A minimum of loose pieces.
B. Complete - Operator has a complete understanding of patternmaking principles. Pattern may have several loose pieces. Requires extreme accuracy for proper registration and irregular built up construction.

Standard per unit

A. Size - Rectangular - Length + Width + Height
Circular - Diameter + Height
B. Hours - Standard time per pattern

Pattern number The PART or DRAWING number which identifies the pattern

Special conditions and remarks

Supplemental information not apparent in the photographs.

Core box code number The symbol of the required core box.

Photograph of the pattern

Photograph of the pattern and core box complete

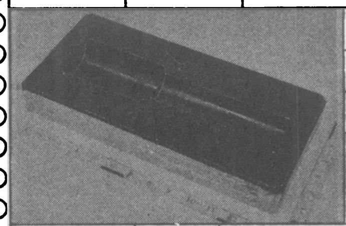
In the case illustrated a standard core is used and no core box is made.

Within this 6 month period, over 300 photographs were taken of different types of patterns made. The workmen had kept accurate time against each of these during their construction. These times were levelled by the observation that the engineer had made during the study. As these times were established, a still picture was taken of the finished pattern and core box with rules along the three dimensions of the pattern and the core boxes to give an idea of size. The length, width and height are added together to be compared to one of the three size classes shown.

The same approach was made for the core boxes except that they are classified by shape and contour.

Figure 9. Numerical List of Core Boxes

RECTANGULAR	ELONGATED	ROUND BOTTOM		STEP	12.22



KIND	FORM	
HALF CORE	REGULAR	SYMMETRICAL
LOOSE PIECES	PATTERN MATERIAL	
0	WOOD	
CASTINGS	PATTERN MAKING KNOWLEDGE	
1	ORDINARY	

STANDARD PER UNIT (STD. PRACT #720)

SIZE: 0 - 12 INCHES; 13 - 30 INCHES ✓; 31 - 60 INCHES; INCHES — HOURS 4.5

PATTERN NO.	PATTERN CODE	SPECIAL CONDITIONS AND REMARKS
DQ 655		
[redacted]	GLD. 1	

RECTANGULAR	ELONGATED	ROUND BOTTOM		STEP	12.22
RECTANGULAR	ELONGATED	ROUND BOTTOM		STEP	12.22
RECTANGULAR	ELONGATED	ROUND BOTTOM		STEP	12.22
RECTANGULAR	ELONGATED	ROUND BOTTOM		STEP	12.22
RECTANGULAR	ELONGATED	ROUND BOTTOM		FITTED PIECES	C12.23
RECTANGULAR	ELONGATED	ROUND BOTTOM		LOOSE PIECES	C12.24

NUMERICAL CODE INDEX

CORE BOXES

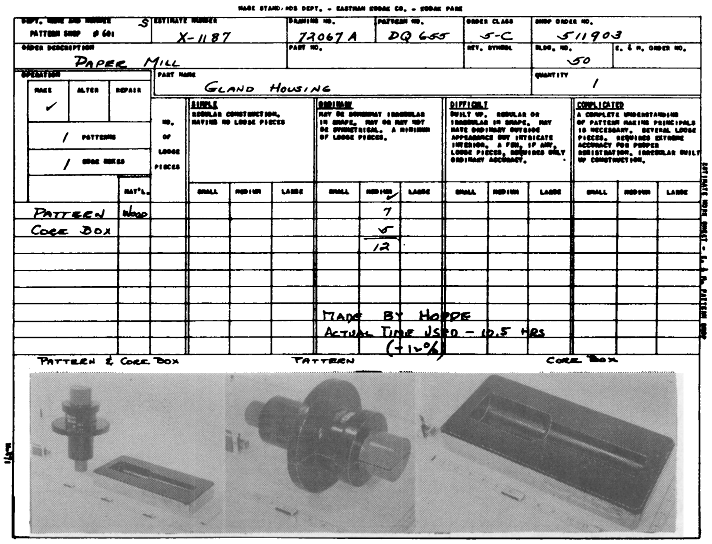
OUTSIDE FORM		OUTSIDE PROPORTIONS		INSIDE FORM		CORE CONTOUR			
RECT.	CIR.	SQUARE	ELONG.	FLAT BOTTOM	ROUND BOTTOM	PLAIN	STEP	FITTED PIECES	LOOSE PIECES
X X X X		X X X X		X X X X		11.11	11.12	11.13	11.14
X X X X		X X X X			X X X X	11.21	11.22	11.23	11.24
X X X X			X X X X	X X X X		12.11	12.12	12.13	12.14
X (X) X X			X (X) X X		X (X) X X	12.21	(12.22)	12.23	12.24
	X X X X	X X X X		X X X X		21.11	21.12	21.13	21.14
	X X X X	X X X X			X X X X	21.21	21.22	21.23	21.24

Note:-
Those core boxes which cannot be specifically classified as above (having no predominant features as indicated in the index) are coded "ODD".

The breakdown of the characteristics of construction of the core boxes is slightly different in detail than for the patterns but follows the same general principles.

This figure represents the form that was used to accumulate the times and how the levelling factor was applied.

Figure 10
Form used
for final standard

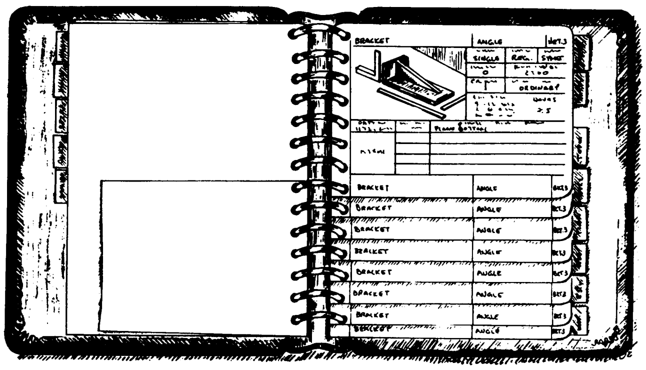


Conventional time studies were made of several different kinds of patterns and core boxes to cross-compare with the times arrived at by the technique just described. These were within a plus or minus 5% which gave us confidence to continue in this approach.

The 5" x 8" pattern and core box data cards are filed by code number in a visible-edge binder as portrayed in this figure.

At the present time there are approximately 350 pattern data and core box cards in this binder.

Figure 11. Standard Data Card Book



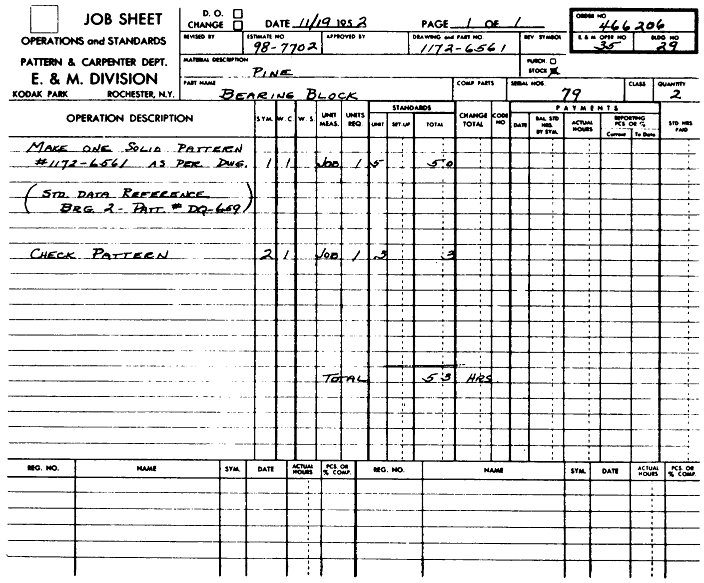
This book is literally a file of standard data times on all the types of pattern and core boxes made to date.

When a drawing for a new pattern comes to the pattern shop, a sketch such as you saw on the first figure is made by the pattern maker. The sketch is checked by the foreman and the standards applicator and a job sheet is started.

The standards applicator and foreman determine the construction characteristics and find a similar pattern and core box in the standard data binder, which gives them the time to allow on this job sheet.

This sheet then acts as a work order and goes with the drawing to the pattern maker who posts his actual

Figure 12. Job Sheet


JOB SHEET
OPERATIONS and STANDARDS
PATTERN & CARPENTER DEPT.
E. & M. DIVISION
KODAK PARK ROCHESTER, N.Y.

DATE 11/19 1952 PAGE 1 OF 1
ORDER NO 466206
98-7702
1172-6561
Pine
Bearing Block
79
2

OPERATION DESCRIPTION						TOTAL
Make one Solid Pattern #1172-6561 as per Dwg.	1	1	Job	1	5	5.0
(Std. Data Reference Brg. 2- Patt. # DQ-669)						
Check Pattern	2	1	Job	1	.5	.5
Total						5.5 Hrs.

hours against the job to the proper column.

When finished, all the job sheets for the week go to Time and Payroll Department where pay and effectiveness are calculated.

If the new pattern to be made does not compare closely as to construction characteristics or size to one in the book, it is time studied as it is made and is then coded and added to the standard data book. These are very few and it is doubtful if we need to study more than 5 to 10 a year.

The net result of this work was to increase the production capacity of this group by 50%. We had always sent considerable amounts of work out to other shops outside the company before this setup was installed. We have absorbed that load plus the growth we have had since 1945 and have reduced the labor force by two men.

In addition, the program was instrumental in installing better equipment and in standardizing methods and finishes which also helped in reducing the cost of this work.

3. Cafeteria

Another indirect incentive installation that has a unique unit of measure and that has been very effective is the one in our dining halls.

There is a main recreation building where the kitchens and bakeries and two cafeterias are located and ten branch cafeterias in other parts of the plant.

This setup serves approximately 17,300 employees per day, of which approximately 4,000 take the complete three-course meal. Several of these serving units must be operated 24 hours a day since quite a bit of our plant is in continuous operation.

Like most industrial cafeterias, ours does not break even and it was the amount of the loss that we were sustaining that prompted the first industrial engineering studies.

In 1947 a team composed of three men, an industrial engineer, a cost engineer and a staff man from the Cafeteria Department went to work on methods to try to reduce costs and increase revenue. Of course we wanted more revenue but not by increasing prices to employees if it could be avoided.

This team worked approximately 1-1/2 years and succeeded in almost cutting our yearly loss in half and in setting up fairly standard job conditions so that it would be possible to apply some form of a wage incentive scheme.

It was realized that if the improvements achieved by this work were not secured by some kind of a measure that there would be a drift back to the original condition. It was also felt that additional improvements could be secured by actual incentive measurement.

The incentive measurement was started in 1949 and was completed in 1951.

The labor costs during this period of time were cut approximately 10% and the revenue was increased approximately 8%.

It must be borne in mind that there were several general wage increases during this period as well as increases in cost of raw materials.

This figure will give you an idea of what happened to the relationship of labor cost to revenue.

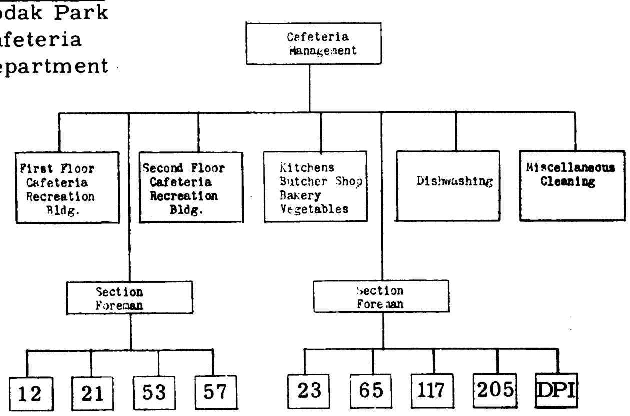
Figure 13a
Labor to Cost Ratio

Year	Average Number of Savings per four-week period	Percent of labor cost to Revenue
1947	--	69%
1948	377,800	63
1949	331,200	60
1950	311,700	56
1951	356,000	57

The work in the cafeteria was broken down into natural work units or groups and conventional time studies were made of each to establish the standard hours required to operate each group.

This figure will indicate what these work units were and their general function.

Figure 13b. Functional Organization Chart
Kodak Park Cafeteria Department



Work units	Approximate size
11 Serving units:	
Bldg. 28, 1st floor	45 employees
Bldg. 28, 2nd floor	23 "
Bldg. 57	25 "
Bldg. 12	7 "
Bldg. 23	4 "
Bldg. 205	3 "
Bldg. 117	3 "
Bldg. 21	6 "
Bldg. 53	6 "
Bldg. 65	6 "
D.P.I.	1 "
Kitchen and Butcher Shop	30 "
Bakery	5 "
Dishwashing	10 "
General cleaning	16 "

Type of labor studies made

It would be impractical to show you all of the studies of the labor requirements but this figure will give you an idea of how we tackled the problem. You will notice that the amount of labor required varies by days of the week.

Figure 14. Hours per serving unit

Serving Unit
....

Operation	Standard Labor Hours Mon-Fri	Sat.	Sun.
1. Sandwich preparation	9.7	4.3	2.3
2. Salad and cold plate preparation	9.5	3.4	2.7
3. Check in and cut pies	3.8	1.0	1.0
4. Check in and cut baked goods	1.0	0.6	0.5
5. Make up butter patties	1.0	0.2	0.2
6. Make iced tea	1.3	0.9	0.4
7. Supply condiments and silver	4.5	0.8	0.8
8. Operate Line #1 (10:30-1:30)	33.5	16.5	14.5
9. Bus dishes, clean tables, vacuum and mop floors	48.5	6.2	6.2
10. Supply clean dishes to line	0.7	0.3	0.3

Standard labor hours are measured for each job in Eastman Kodak's Kodak Park cafeterias to get basic data for plan. Figures above are just a sample of large numbers of time studies that had to be made before the job was done.

Unit of measure

In any kind of a restaurant operation, there are two important factors that measure its success. The cost of operation and the revenue taken in. Our time study engineers decided that the labor that operated our cafeterias could control the amount of labor used and also exercise considerable control of the revenue. This effect on revenue is in many directions. For example, a few of these are:

1. If the cafeteria is kept clean and pleasant, it will encourage patronage and increase revenue.
2. If the food is prepared and served in an appetizing manner, the customer will buy more and increase revenue.
3. If the serving personnel exercise good salesmanship, they will sell more and increase revenue.
4. If portions are standardized and carefully served, it insures maximum revenue.

Accordingly, the unit of measure selected for this work was the amount of revenue that should be collected per standard labor hour needed to operate each unit. This gives each employee an urge to meet or beat the standard labor requirement but to also do everything possible to keep a maximum amount of revenue coming in. It has made salesmen out of every employee and has given them a real sense of proprietorship in the business.

This figure shows how these two factors are combined to secure this dual measure. Again, please notice that it varies by days of the week.

Revenue per standard labor hour is the basic measuring unit. Figure 15 shows how revenue figures are computed. Company averaged 25 representative weeks to get accurate data, covering all seasons of year.

In order to make calculations of pay simple, tables such as you see in Figure 16 were prepared for each group.

Figure 15
Revenue per Labor Hour

SERVING UNIT
Summary Table
Revenue per Standard Labor Hour

Day of Week	Standard Labor Hrs.	Standard Revenue	Revenue Per Standard Labor Hour
Monday	240	$1195	$4.98
Tuesday	240	1195	4.98
Wednesday	240	1195	4.98
Thursday	240	1195	4.98
Friday	240	1195	4.98
Saturday & Sunday	155	640	4.10

Figure 16
Group Effectiveness Percentages

SERVING UNIT
Computation Table
Group Efficiency Percentages

% Effectiveness	Revenue Per Standard Labor Hour Weekdays	Weekends
104%	$5.30	$4.42
103	5.22	4.34
102	5.14	4.26
101	5.06	4.18
100	4.98	4.10
99	4.90	4.02
98	4.82	3.94
97	4.74	3.88
96	4.66	3.80

Method of figuring amount of pay for groups is shown in computation table above. Employees are guaranteed base earning rates, but have no ceiling on amount they can earn.

As soon as the actual labor and revenue are determined for the previous day, the revenue per labor dollar is calculated which enables the employee to see his percentage of effectiveness. This percentage is multiplied by the incentive job rate for 100% to determine hourly earnings.

For supervision's control of costs, a weekly cost analysis sheet is prepared which gives them a picture of the week's operation by groups and in total.

This figure gives you an idea of what such a sheet looks like.

Figure 17
Cost Analysis Sheet

Labor Cost Analysis Report

Dept. 806 - Kodak Park Cafeteria — Week Ending 11-23-52

Description	Actual Hrs	% Effective.	Actual Cost	Revenue	% Cost to Revenue
Main Cafeteria - 1st Floor Serving Unit	669	107	$ 1073	$ 3113	34
Main Cafeteria - 2nd Floor Serving Unit	1508	108	2620	8190	31
Branch Cafeteria - Bldg.12 Serving Unit	293	100	556	1700	32
Branch Cafeteria - Bldg.23 Serving Unit	221	104	381	1427	27
Operate Kitchen Unit	1362	106	2574	25,990	9
Dishwashing operations (Main Cafeteria)	405	104	675	13,079	5

Figure 18 is for the individual operators to give a picture of the week's operation.

Figure 18. Premium Posting Sheet

KODAK PARK CAFETERIA

Premium Posting Sheet — Week Ending 9/14/52

Reg. No.	Name	Monday Actual Hrs	Monday % Effect	Tuesday Actual Hrs	Tuesday % Effect	Wednesday Actual Hrs	Wednesday % Effect	Thursday Actual Hrs	Thursday % Effect	Friday Actual Hrs	Friday % Effect
806202	John Doe	6	108	5	110	6	107	6	106	6	106
806286	Isabell Brown	8	104	8	106.	8	100	8	98	8	102
806441	Frank Black	8	98	8	110	8	95	8	104	8	100
806314	Bertha White	6	104	6	105	6	98	6	102	6	108

Tools of this kind are only as effective as the supervision that operates them.

We have been most fortunate in having supervision that has been interested and capable and the results have been excellent.

We have accomplished:

1. Reduction of operating costs
2. Increased revenue
3. More accurate scheduling of work
4. Better utilization of labor
5. Better utilization of facilities
6. Improved quality of workmanship
7. Increased the pay of our employees
8. We have happier employees who take a proprietorship attitude.

Figure 19
Finished Food Prices

Samples of Food Prices - Kodak Park Cafeteria

Roast Beef) Potatoes) Vegetable) Bread and Butter)	.50
Pie	.12
Coffee	.07
	.69

Vegetable Soup	.10
Egg & Olive Sandwich	.25
1/3 Qt. milk	.10
	.45

Baked Hash	.30
Roll & Butter	.05
1/3 Qt. milk	.10
Ice Cream	.10
	.55

Hamburg Sandwich	.20
Pie & Ice Cream	.17
Coffee	.07
	.44

Special Hot Meat Sandwich	.40
Pie	.12
Coffee	.07
	.59

This installation required the time of approximately two time study engineers for 1-1/2 years.

It requires approximately one-half of a clerk's time to do the necessary clerical work for approximately 225 employees.

These three jobs are only a small part of the indirect work that we have covered by incentives at Kodak Park

They were chosen for discussion because in each there was something unusual in the approach that the industrial engineer had to make to solve the problem.

Generally speaking, indirect work is more difficult to cover with incentives than direct work. For this reason, it is highly desirable to have the organized approach that trained engineers make to a problem.

While it may be more difficult if a good job is done, we believe that the returns are even greater than the returns from the measurement of direct work.

The application of direct workers even though not on incentive is apt to be better because of definite objective production measures.

Because the measures are more obscure in indirect work, it is harder for supervision to judge whether or not people are working effectively. The people themselves, of course, are just as aware of this, with the inevitable result that performances are not very good even by day-work standards.

All of this adds up to the fact that if the industrial engineers will sharpen up their ingenuity so that they can find logical units of measures and can devise systems of measurement that are not too expensive to install or maintain, they have a field of work that can be very productive.

LUNCHEON SESSION

Session Chairmen: Robert G. Sproul, Berkeley, January 31, 1953
Neil H. Jacoby, Los Angeles, February 3, 1953

Dr. Robert G. Sproul
President
University of California

A university president, by virtue of an old American tradition which accords to him an unearned reputation for omniscience, is expected to welcome important groups such as this one to his campus (in my case eight campuses), and to present to them the wide variety of distinguished guests who are imported to address such conferences. Moreover, it is decreed by custom that each of these presentations shall be prefaced by remarks appropriate to the scholarly discipline or professional activity which has drawn the conference together -- about which the president is usually much more ignorant than any of those to whom he is speaking.

Thus placed constantly in jeopardy, a president, and especially one who has been twenty-three years in office, naturally develops a technique which he fondly hopes will enable him to "get by," i.e., he confines his remarks to presidential platitudes expressed in words designed to conceal either thought or the lack of it. This technique, I report, seems to work reasonably well on all occasions except those in which wealth of ignorance is combined with poverty of interest, as for example, he is called upon to illuminate the subject of egg candling, or the night life of the gopher. Then the going is really rough.

Fortunately, our luncheon today does not challenge me with this ultimate in hypocrisy, for I do know what an Industrial Engineering Institute is, and I do have a nodding acquaintance with the nature of the problems to which its members direct their attention. After all, I was graduated from the College of Civil Engineering on this Berkeley campus, just a year or two after Columbus discovered America, and I can still dredge up from memory, or from random readings in the Trans-Am-Soc-C.E., an elementary idea or two, and "get by" with an audience which has a sort of fraternal feeling for me, and is not unduly critical.

Moreover, I have a keen interest, as President of the University, in this Fifth in the series of Industrial Engineering Institutes, although not necessarily in fifths in general. Institutes such as this represent a concept of university service to which I am wedded, which I cherish, and which I am eager to see produce and multiply. For university education is only a short term vaccination against the potent virus of ignorance. Regular booster shots are imperative if any safe degree of immunity is to be maintained. This prescription is equally valid for professors and for practicing professional men and women. Believing these things to be true, the University feels that it has an obligation to draw professors and practitioners together in conferences such as this, in order that both groups may renew their mental strength and build up their resistance to the pernicious inroads of progressive intellectual decay.

The institute as a device for life-long learning is peculiarly applicable, it seems to me, to industrial engineering which, if I understand it correctly, is designed not so much to deal with new problems, as to try to solve old problems which have plagued society through all the years of the industrial revolution. In other words, industrial engineering is an extension of engineering knowledge and procedures beyond tools, machines, and structures to the systems and organizations of the human beings who must use and operate them. As such, it is essential to the vitality of a society which has set for itself a pattern of progress founded upon free enterprise and earned profits.

For such a society to endure and prosper, it must not only facilitate the production of quality goods at competitive prices, but it must, also, increase the earning power of its members so that there may be more and more solvent buyers of whatever is produced. Increasingly in the modern world, moreover, competition among industrial and commercial organizations exists not only within a single nation, but also internationally. And this competition is coming to be less and less on the basis of monopoly either of raw materials or mechanical equipment, and more and more on the basis of efficient organization of both men and machinery. Inevitably, in response to these forces, the standard of living becomes a positive goal rather than a by-product, and the field of operation of the economic soothsayers and the ideological charlatans is definitely circumscribed.

So much for the academic arguments that led me to accept this assignment. The real reason for my being here, of course, is the lady whom it is now my pleasure to present to this audience -- an alumna upon whom the University of California has conferred three degrees -- the bachelor's, the master's, and the Doctor of Laws. Providence, of course, has conferred the MA upon her more bountifully than the University, but we have done our best, and we are proud of it and of her, in all her fields of productivity. As a pioneer and perennial leader in the profession of industrial engineering, she has earned a place of honor in this or any other institute of its kind, and I am confident that we shall profit by listening to the words of wisdom distilled from her fifty years of experience in seeking "the one best way." It is with pride, then, as well as pleasure, I present to you Dr. Lillian Moller Gilbreth.

THE FUTURE OF INDUSTRIAL ENGINEERING

Lillian M. Gilbreth
President
Gilbreth, Inc.
Montclair, New Jersey

Nothing can be more challenging than a subject which turns our eyes toward the future. It means considering the problems of today not only as the result of the problems of yesterday, but as essential factors of the problems which still develop tomorrow. In the light of the long evolution of mankind, Industrial Engineering is a very new branch of a comparatively new science. But to the people working in this field, largely young and enthusiastic, it is a most important area of interest, and what is to happen within the profession is of a profound significance to them.

The Industrial Engineer is intrigued with his field of activity. He is vitally interested in the techniques which it includes and in the possibilities of applying these techniques for the service of mankind. He recognizes very fully he cannot hope to solve the problems which come to him without help, but he is very eager to contribute all that he possibly can and to demonstrate that he has a right to a field of his own, and that he can face and attempt to solve its problems with enthusiasm and with a real desire to be helpful. Often he becomes so engrossed with a special technique which he is using and which interests him without realizing that he cannot do his best work in such a technique without knowing its inter-relationships with other techniques and its place in the whole field of industrial betterment. He must take pride in the fact that there are so many fine groups as those who are sponsoring the programs on this campus and on the sister campus, and their realization that he has a part in their interests and in their field of activity. This should lead him to consider all of the related problems as they come to him in his membership in these sponsoring groups; and then to look at his problem not only intensively but extensively as well. As a matter of fact, many of the most interesting and challenging problems which face him in the future are of the extensive variety.

Like all of us, the Industrial Engineer has his problem as an individual; as a member of a family; as a citizen and therefore a member of a community, of a state, of a nation and of the world; as a volunteer of various activities which he selects and where he contributes where he is most needed or where he can give the most as well as get something in return for his contribution; and as a person on an industrial or business job, who has a stake there and has a contribution there and is willing to be trained to use his capacity and to make his contribution as large and significant as possible. In all these capacities he does and must, of course, look at the future.

Now, looking at the future is at the same time a stimulating and frustrating experience. Frustrating, in that our first impulse is to say, we have no idea what this future is to be and, therefore, looking at it cannot be an immediate concern to us insofar as our getting ready to meet this future is concerned. This, of course, as we come to think more closely, we realize is really not true. The making of the future may not lie in our individual hands or in the hands of any group to which we belong, but the making of the future certainly does lie in the hands of the people who will be a part of that future. The people, who are our children--members of the human race, can by their decisions determine what that future is to be. Many of us, as we look into that future, turn swiftly and often back to the present, in order to see what we can do to further the things which will be constructive and to eliminate or delay the causes of things which will be obstacles, which will make our future less secure and less desirable to any of us.

Fortunately, the engineer, whatever his type or variety, belongs to the scientific group who have been trained from the very early days in the disciplines of stating a problem as clearly and as simply as possible. This is some help in looking toward the future, in every capacity that any one of us has. If the problem is entirely beyond our ability to comprehend, or to state fully, it is our job to turn to such aspects of it as we can state clearly and fully and where we can gather means to solve it. It is our job to rank the problems--rate the problems--in such a way that we turn first to those where we can do something definite. We must have in mind constantly that, as conditions change, opportunities may come where problems which had seemed to be beyond our participation or help may become ones in which we can participate. The engineer has a great opportunity here in working in the interdisciplinary field, as it's coming to be called, where he is with people who have had other kinds of training, people who have had other avenues of going at problems, and who may be able to include him in solution of problems which he could not possibly undertake alone. He may find also that in going in to one or another type of service--adding volunteer activity or citizenship activity to his job activity, or working out problems in the related fields, of the family, or the home, or the community--new slants and new approaches to problems and new problems where it is a part of his opportunity to give service, may come into the picture. As he looks at the field of engineering, the Industrial Engineer will share with all others the feeling that the discipline he has had, the type of training available to him in stating of problems, in searching for resources for solving these problems and of realizing that the resources are constantly expanding, is one of the greatest assets in this whole field.

The Industrial Engineer, new, young, inexperienced, in many cases, profits so much by association with those who have been in related fields of engineering that he is overcome sometimes at the amount he has to learn and the little he has to contribute. The thing that he does have to contribute would seem to be his realization of the importance of the human element. As far back as engineering extends and long before its days of becoming an accepted disciplined science there has been a realization that its use was for the benefit of mankind. The time is not so remote when there was a frank and free statement of the belief that his work concerned itself with human beings as well as being done for their benefit. So that we add to the use of nature for the benefit of mankind the utilization of human nature. The Industrial Engineer has had the importance of the human element brought very clearly to his attention because he studies the work situation, whether this is in the shop or out on construction, or wherever people are at work. He constantly finds that unless the human element is adequately considered, his plans for putting through activities can be much delayed until satisfying human relations have been provided for. It is evident in the work of the pioneers in this field, as represented by those in the field of scientific management, that where this thought was in mind and where very definitely inclusion of the worker and of every human being involved in the activity was a part of thinking, procedures went through smoothly and the techniques as they were evolved produced the desired end. On the other hand, where the human element was neglected, the finest plans for technical development failed.

Meetings like this where Industrial Engineers gather to discuss their problems and to look at the future problems emerging, are appropriate occasions for evaluating what has been done and what needs to be done. Engineering has been defined; what is Industrial Engineering? It seems to concern itself with industry and with business. But actually, it concerns itself with anything going on where work is being accomplished. The moment we realize this, we see that many of the newer fields into which Industrial Engineering is penetrating--government, the home, the hospital, the library, the utilization of the physically handicapped, the older worker, and above all, the new and tremendously interesting and challenging problem of automation--all show the tremendous expansion of the field. It is not, so far as the field of application of Industrial Engineering is concerned, a future which narrows but a future which broadens its horizons.

The future makes certain demands on all individuals which the Industrial Engineer must recognize. Then, as now, we shall expect individual adequacy--people who are physically fit, mentally alert, emotionally stable, and socially adjusted and happy in participation. By physically fit, we mean making the best possible use of such physical equipment as they have, in spite of handicaps. Many who are physically handicapped make far better use of what they have than those of us who have no physical handicaps which are apparent. The future also demands people who recognize that they are a part not only of groups but a part of teams, and are ready, willing and happy to become a part of team activity. There seems to be an increasing realization that functions are vital to teams; that the person who occupies a certain function is to be judged as a person who has this responsibility and meets it adequately or not so adequately, rather than as an individual who has chosen to occupy the function and is interpreting it in his own fashion. For example, on a boat, the man who is captain has that function and from him can be expected the things which a captain should do and not an individual who has gotten a certain job and is interpreting this job to utilize his own assets and to compensate for his own liabilities. The future has, we believe, also a right to ask that people shall have both technical adequacy or capacity, and also skill in human relations. Understanding the art of communication, knowing how to get on with other people smoothly, and having back of both the human relation skills and the technical skills needed must be a warm, friendly, approachable nature which makes it a pleasure to function in both respects.

The future has a right to demand of every one of us who happens to be an engineer, that he recognize and accept the disciplines of engineering, and that he recognize a responsibility to continue his training and his education so that he may more adequately fill the responsibilities he has and at the same time take on new responsibilities for which that education and training may prepare him. In the past sometimes engineers have felt their responsibilities were only in the fields for which their training prepared them and that calls from other fields like the family, community service, volunteer work, citizenship, etc., should not be made to him but to other people, he giving full time and energy to the technical specialties to which he prepared himself. The Industrial Engineer of the future will realize that the calls upon him will be many, will take him to many countries, many places, many activities, and that they may demand of him things which he has not received as part of his engineering training. These things we have already referred to, obliquely at least, in mentioning the need for being socially adjusted and emotionally stable. If the Industrial Engineer is the kind of person who feels inferior because he does not know the niceties of polite behavior, because his grammar is a bit defective, his spelling bad, his enunciation not agreeable, then it is essential to remedy these defects. Intelligent people everywhere realize that lapses from some of these already outmoded standards are not a serious thing and that they have no real importance as compared to a warm friendly nature, technical adequacy, integrity, and willingness to work hard. But it is in most cases so simple to get the type of education and training that will remove such deficiencies that it is a shame to face a future without getting adequate preparation for it. Perhaps it is scarcely necessary to emphasize that jobs labeled "Industrial Engineering" will by no means cover the jobs open to an Industrial Engineer in the future. It may be that we shall be intelligent enough to widen the scope of the job descriptions and keep our lists of opportunities continuously up to date. If so, we shall improve the product of the past, where too often we have failed to note that Industrial Engineers have gone into top management, into finance, into sales, into national or international planning, and into fields where we have not primarily expected that opportunities of such importance would develop or would develop so rapidly.

This has many implications in the field of education. Those who are concerned with the training and the education of the Industrial Engineer must bestir themselves to see that everything possible is done to plan for his getting the material he needs as promptly and as adequately as possible. Young and older Industrial Engineers should be asked what things which were not a part of their pre-college or university training might have helped them to use their opportunities in universities and colleges more adequately. In the same way, those who are doing graduate work should be canvassed to find out what sorts of things they should have had in their preparation which would make taking on of research and finding these projects an easier thing than it is at the present time where many an Industrial Engineer has to go back to do preliminary preparation which could have been done in his undergraduate years. Above all, people who have spent time on the job should look back on those years to find out what they wish might have been different. Perhaps the most important thing in the educational field, however, as we face the future, is that we realize education and training are a life-long process. Next to that perhaps comes that we re-appraise the people who can help us; that we do more to encourage librarians to help plan the curricular and assemble material for the Industrial Engineer on the job. The librarian looking to the future is already realizing that radio, motion pictures, television, visual education of all sorts, and probably new types of education of which as yet we know nothing, are a part of the resources she can bring to people who come to her for guidance.

While undoubtedly the field of Industrial Engineering will develop men who are in the education and training end who can give more adequately the preparation needed, we cannot continue to feel that all that is required will come from our own area. We must work continuously with the other disciplines related to ours, the ones we already recognize as such-industrial psychology, industrial psychiatry (only now in the making), industrial physiology, and every other related science known and as yet unknown which will have an application in the industrial field.

Perhaps it is unnecessary to say that the work-life is not the complete life of anyone and that in one's leisure time there is a necessity to have far better training, far better knowledge of what would be helpful and how one can get it. The Industrial Engineer needs education in the so-called cultural areas--history, art, music, and everything which can make his life more interesting--not only because much of this material will be of work-use to him as studies in rhythm, in pace, and in motivation become more and more general, but because in his own life he needs this to complement what he has. Perhaps it might also well be said that he needs to think about these in choosing his wife and in setting up his projects for the use of family time, because teamwork is becoming more and more a part of every institution of our life. The Industrial Engineer has a fine job and a fine opportunity to participate in teamwork during his training period and out on his life work. He should be able to be of great help as a participant, a director, and a enjoyer of teamwork in family relations and in social situations.

Fortunately, the Industrial Engineer--and all of us--have a great resource in solving the problems of the future --in automation. In his provocative paper, and in his list of references, Professor Frank Shallenberger has shown us what power can do, used constructively. As he says, automation is not new. But the word itself is only now appearing in our desk dictionaries, and we need to know and use it, and explore all its possibilities.

Destructively used, automation could terminate our forseeable future on this planet. But constructively used, it can make life richer and more satisfying to more people. We must use it constructively! The machine age lifted many burdens of drudgery and repetitive activity. But unwisely used, machines and allowing mechanism to set the pace of human beings could create more things at the expense of satisfying the people who worked with them.

It is the challenging job of the Industrial Engineer to see that automation frees people. It can! Our work simplification that produces rhythmic patterns of repeated motion cycles has always helped in machine design. Now we can expand our thinking to utilize power more effectively --and design mechanized production equipment that utilizes power most effectively--rather than that which copies the way the human body works. We can help find and develop men and women who can design, produce, install and maintain such equipment. We can help find jobs for the rest of us. We can, if we wish, sometime reduce the working day to four hours--yet supply people everywhere with what they need. We can help make sure there are no "displaced" people, but that a job is available for everyone. And we can prepare to contribute to leisure-time activity that training in competence which is basic to any success we have had.

Automation must mean freedom, not slavery. We must help to make sure that it sets us all free. Not free <u>from</u> drudgery--physical or mental alone--but free <u>to</u> create satisfying, serene lives.

All this may seem a highly optimistic and perhaps almost unrealistic attack upon the future, the problems of the future and the part of the Industrial Engineer in stating and solving them. If so, I make no apologies for this; it is obvious that what we can do to prevent calamity to the world we should do to the utmost extent possible. But on the other hand, it is, it seems to me, our great job to try to see what can be done to utilize what we have, and to hope for, to work for, and to be a part of preparation for a future which may be so much better than the present or the past that we may be proud and glad to have contributed toward it. The fact that this is an extremely difficult problem, because we are including in our thinking everybody in every country of the world, because we are trying to look into the great fundamental problems of the increase in the world's population, the longer length of life, the adequate feeding of people, the giving of opportunities to participate in getting economic and emotional security, and because all of these sorts of things are of increasing importance does not mean that we cannot be interested in them and help; but it certainly does mean that our final effort should go into our own field and into our own contributions to it. Having the problem of at the same time extending our field of interest and focusing our field of interest, having the problem of generalizing what we have so that we can meet demands from correlation and integration and utilization, while at the same time pursuing and developing our specialties, we cannot say that we see a time of idleness, of despondency or of inertia before us. The future, whatever it may bring, is challenging, is stimulating and is worthy of every possible effort we can give toward making it a better one than it would otherwise be.

<u>References</u>:

"Executive Suite" -- Cameron Hawkley

"The Man on the Assembly Line" -- Charles R. Walker and Robert H. Guest

"Automation" -- John L. Diebolt

NEW *Industrial Engineering* TECHNIQUES SESSION

Session Chairmen:
Ewald T. Grether
Berkeley, January 31, 1953
C. M. Sandland
Los Angeles, February 3, 1953

VALUE ANALYSIS - "A PLANT WIDE CREATIVE COST REDUCTION PROGRAM UNDER PURCHASING LEADERSHIP"

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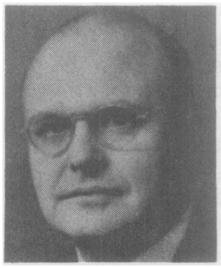

On the average, one fourth of manufacturing cost is unnecessary. The extra cost continues because of patterns and habits of thought, because of personal limitations, because of the difficulties in promptly disseminating ideas, and because today's thinking is based upon yesterday's knowledge.

I will show you a program which is surprising us in its abilities to cope with these limitations. We call it - Value Analysis. It is a Plant Wide Creative Cost Reduction Program under Purchasing Leadership.

In the act of evaluation, Value Analysis generates tangible suggestions which eliminate unnecessary costs.

Value Analysis is a creative study of every item of cost in every part or material considering other material, newer processes, abilities of specialized suppliers and possibilities for engineering re-evaluation. It focuses engineering, manufacturing and purchasing attention on one objective--the same performance for lower cost. It is not a substitute for the engineering and manufacturing cost reduction work which is carried on by every company. It is a supplement. The results reported today are in addition to those developed by the good normal cost reduction activities of a company. It promotes no suggestions which would lower quality. Its job is to get the same, or better, performance for lower cost.

I will further illustrate: What Value Analysis is... Why it is plant-wide... Why it is under purchasing leadership.. How it is done... and What it accomplishes.

WHAT IS "VALUE" ANYHOW?

Value is not inherent in any product. Value is established by comparison. The relationship of the function or service performed by any part or material to the lowest dependable cost for obtaining that function or service establishes value. The value of a pencil is the minimum cost of something to appear well, handle well and write well. The value of a broom cannot be higher than the minimum cost of other methods for keeping the floor clean. The value of a light bulb is the relationship of cost to light. Establishing value always means comparison. The value of Miss Hollywood, bathing in the California sunshine, is not established by a chemical analysis of her blood and bones, but by a direct comparison with the Misses to her right and to her left, comparing the abilities of each to please the eye, the imagination and the sponsor. Without an exceeding broad base of comparison, no true Value Analysis is possible.

As engineering accepts unchallengeable responsibility for dependable performance, so purchasing must accept responsibility and accountability for value. Purchasing must guarantee to management that each dollar of cost buys a real function. It must either improve the operation or the appearance of the product.

Purchasing must know that every dollar it spends plant-wide is "working." For example, we saw yards of asbestos paper rolled out along the floor under a paint conveyor catching paint drippings. "Why an expensive asbestos paper for so simple a function?" To meet the fire safety code!" Probably yesterday's thinking again! - To evaluate asbestos for catching paint drippings starts a broad inquiry to makers of special papers. Sure enough a non-burning paper is obtainable. It costs less than half and does the same job. Again, prompted by Value Analysis, the buyer, instead of continuing to buy steel bar, searched out its use in the factory. A small shaft and a small hub were machined separately, then assembled, costing 60¢. This sent him on a broad search for today's methods and brought a supplier who would use the steel shaft as an insert and die cast the hub onto it, reducing cost from 60¢ to 22¢, providing the same performance for about 1/3 of the cost. Again, (Figure 1), the Value Analyst seeing small gaskets being made by a machinist in lots of a few dozen reached outside of the plant, finding gasket making specialist companies - reduced the cost from $2.15 to $.15 each.

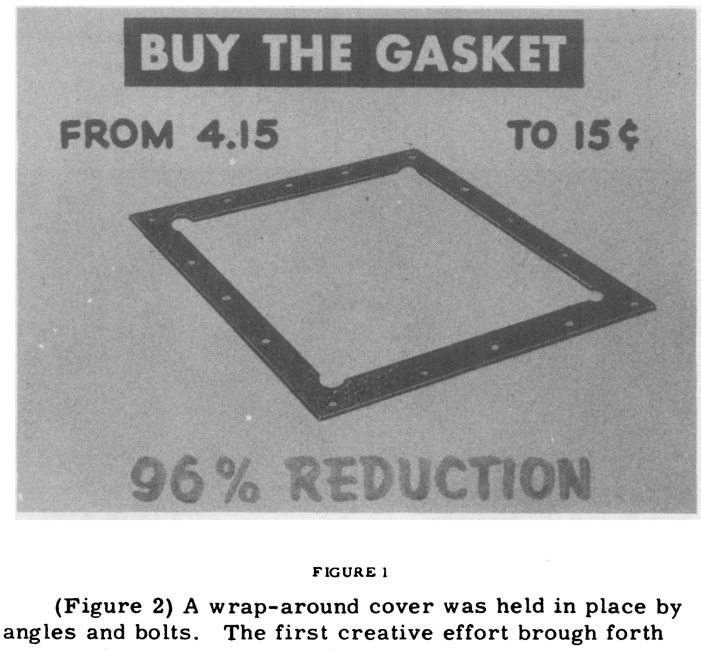

FIGURE 1

(Figure 2) A wrap-around cover was held in place by angles and bolts. The first creative effort brough forth (Figure 3) metal strapping for the same job, cutting the cost 44¢ each. Prompted by this new information, and by this

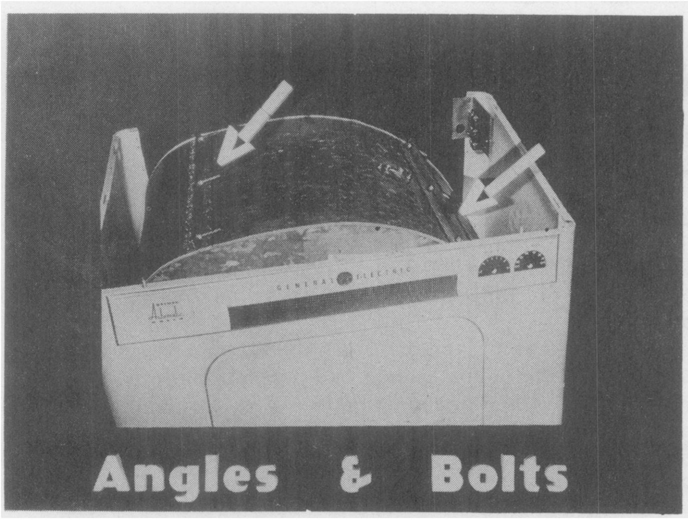

FIGURE 2

FIGURE 3

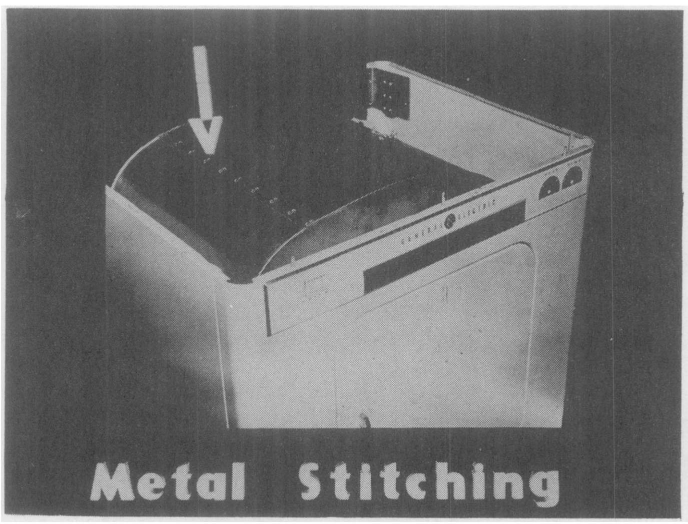

FIGURE 4

new stimulus--creative thought by the engineers on the job changed it to (Figure 4) metal stitching with a further saving of 15¢, the resulting performance was identical, with a much nicer appearance and cost was reduced a total of 59¢, $35,000 per year.

This broad base Purchasing Value Analysis Program must evaluate every part or material whether all, little, or none of the work on it is done within the plant.

VALUE PROGRAM IS A "NATURAL" FOR PURCHASING LEADERSHIP

To evaluate is to compare. To truly analyze value is to compare broadly and intensely. The door of the Purchasing Department is by the nature of the job open to all industry, to all ideas, to all methods, and to all products. It is open to all peoples who may have a process or material or part or service which will do the same job at lower cost, thereby setting the value line for other items. Purchasing's day to day job brings in this vast reservoir of evaluation and Value Improvement information. Expect purchasing, then, to carry its rightful share of opportunity by guaranteeing to the Company management, Value, in exchange for every dollar of the stream of dollars being daily handed out by its buyers.

Value study is function study--no function-no value! Function either pleases people or does a job. Through purchasing's wide-open doors, the best vendors and the best specialists have straight-line opportunity to study the function purchased by each dollar of cost and to suggest better means for lower cost. Only this broad study is true Value Analysis.

For example, a buyer traditionally bought brass rod as requested. Spurred by the Purchasing Value Analysis philosophy, he sought out its use. He found that it was being machined and milled into U-shaped terminals and screw caps for the purpose of holding a wire for electrical connection. He immediately offered opportunity to specialist suppliers who make terminals from tubing showing them the function of the parts. They provided terminals fabricated from copper tubing which did an even better job and saved half of the cost - $25,000 each year.

Or take the case of the buyer who was buying 20,000 screw machine (Fig. 5) studs each year at 10¢ each. Not content to spend his Company's money without a true Value Analysis of each part, he put the project up to some good

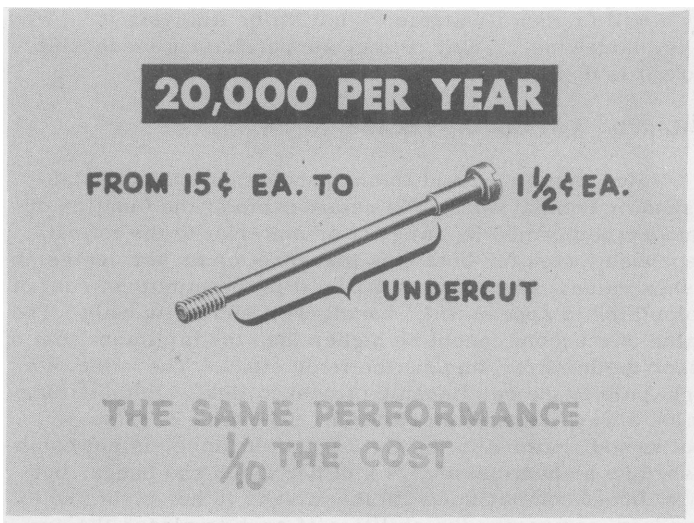

FIGURE 5

upsetting firms, again following the one and only channel for evaluation - broad comparison. Several told him it couldn't be made on an upsetter, but one said, "I think we can do it. Where the undercut is required, we will roll threads for part of the stroke and interfering threads for the rest of the stroke. We think that this will strip off all of the metal at the undercut." He did it. It worked, and the cost went from 10¢ to 2¢. Identical performance for one-fifth the cost!

Again, a manufacturing unit constantly used and specified a liquid cement hardener. It costs several dollars per gallon. The Value Analyst pressed a broad study of the material, made its function known to supplier specialists, and found that it was compounded of a few common simple ingredients. Its cost became 25¢ per gallon, the same performance for 1/10 of the cost!

HOW IS PURCHASING VALUE ANALYSIS DONE?

Good seed only grows and bears fruit when it falls in fertile soil and is properly nourished.

So the creative Cost Reduction Program we know as Value Analysis consists of:

1. Buyers and specialists trained in Value Techniques and in human relations.
2. Carefully studied techniques for operating in the human relations climate and for constantly improving it.
3. The necessary operating information. This includes--specific knowledge, specialist information, idea sheets, new products and processes information, etc.

START WITH VALUE ANALYSIS TRAINED BUYERS

As so well said in the National Association of Purchasing Agents new book, "Cutting Costs by Analyzing Values" -- "the buyer must determine the minimum cost at which the function of a desired material or service can be secured. To do this, he must first know the desired function and then search out, learn and study every alternate method for achieving it", that is - the cost, the advantages and the disadvantages of each method. The Purchasing man carrying the initiative and working with those who are informed and those who are responsible makes an intense study endeavoring to promote lower cost by weighing the function obtained for every expenditure on the scale of functional performance.

He studies similar products or services or materials. He studies the use to which each feature of these items is put and he determines whether functional performance can be purchased at lower cost by eliminating, substituting, simplifying or grouping. He studies the special functions which may be obtained from the special skill, knowledge and techniques of Specialized Suppliers. Using this broad approach, he can more nearly assure value on each specific item.

NOW TRAIN VALUE ANALYSIS ENGINEER SPECIALISTS

The "Motive Power" is the Value Trained Specialist. He is selected for:

1. Engineering or methods and planning experience supported by a general understanding of the properties of materials and their uses.
2. A good creative imagination.
3. Enough initiative, self-organization, and self-drive to start and complete their projects with little if any supervision.
4. A feeling of the importance of value.
5. A mature personality, stable, not easily discouraged
6. The desire to work and deal with others and the general knowledge of how to do it.

Value Analysis specialists must work with all of the facts. They require drawings, specifications, planning cards, and all costs. In discussion with the responsible engineer, they familiarize themselves in general with the basic operation and problems of the product. After a similar study of manufacturing operations, their intense program of seeking out, adapting, evaluating, and applying follows.

Theirs is a full-time job. It must be intense and thorough. It requires serious thought, hard study and immediate action. It is not a "second" activity. They develop the ability to pick out, because of experience and training and contact with similar items, those items of cost which do not represent value. They develop ability to immediately start actions in the direction that will promptly eliminate unnecessary costs. Value Analysis training programs and "on-the-job" Value Analysis work develop capable specialists.

SPECIALISTS USE VALUE ANALYSIS JOB PLAN

The Plan operates on each job through six phases - In the...

1. Information phase, The specialist secures all pertinent costs, facts and drawings. He learns the basic engineering and manufacturing facts.
2. In the Speculation phase he creates and generates every possible solution, consults others, and systematically explores various processes, materials, and rearrangements of parts.
3. In the Analytical phase, each idea is evaluated carefully. Those which have road blocks which still seem unsurmountable are sifted out and a program is set up to pursue each remaining idea vigorously.
4. In the Program Planning Phase, the job is broken down into a series of functional areas. That is - a fastening job--a support job--or a surface protection job. Top specialists, both in the company and outside are consulted and given opportunity to suggest their ideas, their materials and their products, to more economically do a better job in each small restricted but important area.
5. In the Program Execution Phase, the Value Analyst constantly follows up with the supplier specialist. He goes back for modifications until the obvious roadblocks are removed and definite tangible suggestions for securing the same performance at lower costs result.
6. Finally, in the Concluding phase, the Possibility Sheet is prepared. Pertinent supporting studies and detailed information are provided to the responsible party and the Value Analysis Specialist moves on to the next job. A typical Possibility Sheet shows a few simple important and pertinent words and usually a simple "before" and "after" sketch. This suggestion sheet immediately becomes property of the management and is given whatever support and follow-up management feels it earns. (Figure 6) A suggestion sheet, for example, will show 100,000 gears - cost, $58.00 per M. Miniature zinc die castings would cost $8.00, nylon castings $10.00 - "make it from pinion rods" - $21.00, "make it from powdered bronze" $19.00 or "make it from powdered iron" - $21.00. The target savings of $5,058 shows the effort the management is justified in spending to successfully adopt this suggestion.

"Good seed" consists of Value Analysis Trained Buyers and Specialists using good Value Analysis Techniques.

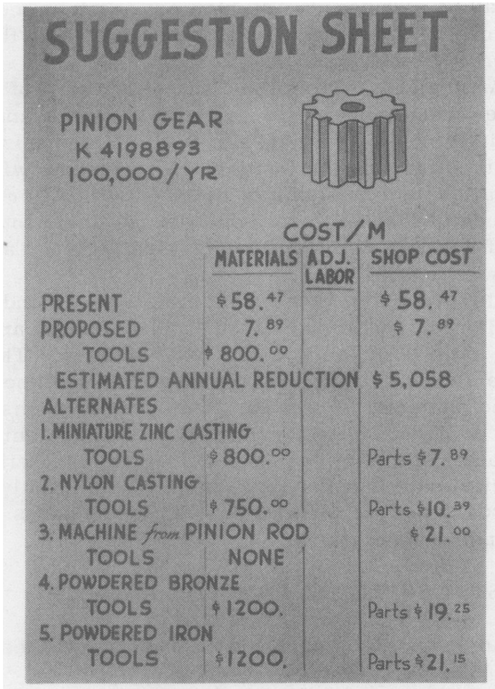

FIGURE 6

CORRECT HUMAN RELATIONS ARE THE KEYSTONE

The "Fertile Soil" is the human relations climate. Purchasing Value Analysts must look a little into engineering, a little into manufacturing methods, and a lot into the Purchasing area. In so doing, however, they always work through the engineers, the manufacturing methods men, and the buyers, never around them, thereby strengthening each man in his own field.

Good Value Analysis activity establishes the attitude of the Value Analyst and the human climate in which he works. In our complex competitive society, no one individual is "good enough" to do any job as well as it need be done. Be his field the design of mechanical equipment, the compounding of chemicals, the adaptation of the best processes or the searching out of the best vendors, he cannot possibly be well enough informed to do the perfect job. Each can always do better by searching for, reaching for and using help.

This attitude brought a managing engineer whose group had just completed a redesign of a very successful and widely used product to the Value Analysis Specialist saying "Our new design is more efficient, requires less space, and costs less than the present, but we know that ten years from now we will look at it and say - "How could we have been so blind? Why didn't we do some things differently? Look it over and tell us some of those things now!" Actually, after Value Analysis, one major component was further improved and its cost reduced 20% as the result.

A product engineer used small springs costing $10,000/year. The product, the drawings and the story of function were provided to a spring company's chief engineer. "For that function, what do you say that we should use?" He made five suggestions varying in cost from $2000 to $10,000 per year. He supplied samples of each grade and a page of test data on each. The engineer glanced it over and said, "My Gosh! Why can't we have this kind of information for all of our decisions?"

In the top league of Human Relations Techniques is the Suggestion Sheet, already shown. These clear concise tangible suggestions containing the dollar sign are not followed up by the Analyst. He sets forth his case and walks away. None of the reminding and needling which has often created bad human relations in the past!

Purchasing Value Analysts make no savings claims. The suggestions which they develop materialize as savings in either the engineering, the manufacturing methods, or the purchasing areas. There must be no flag waving, no claims of big dollar totals to alienate others. The only report issued is the item by item suggestion sheet.

Proper human relations every day accomplish far more in the long pull.

Having taught Value Analysis techniques and having achieved objective constructive attitudes, it remains to provide specialists and buyers alike with the information which they need to meet their opportunities. This is done in several ways.

SPECIFIC INFORMATION IS THE BRIDGE TO VALUE

1. Specialty companies who can provide specific parts or services or materials and who are good enough to actually excell in their own narrowly restricted fields are constantly searched out and this information is made available to all.
2. Specialists in the various laboratories, engineering departments, manufacturing departments and purchasing departments throughout the company who have achieved a position of leadership through unusual knowledge and experience in a specific area are brought into contact with Value Analysis people.
3. Purchasing agents and buyers throughout the company are taught to call upon other buyers and purchasing agents in the industry, for specific information concerning suppliers who excel in their respective fields.
4. Important among the information provided to assist the specialist are "Idea Sheets" which list dozens and dozens of methods by which unnecessary costs have been removed from various products. For example, a typical page has three major headings, the first "Eliminate the part." Under it, are items like "change any other part to perform its function." The second, "Simplify It" -- containing items like "use roll pins to eliminate reaming" and the third, "Alter it so that a high speed method can be used" contains items like "drill and tap small parts in the strip before cutting apart."
5. The now well-known Value Analysis Ten Tests For Value are used. As each part or material or service is studied, these ten questions prompt and direct thought.
   1. Does its use contribute Value?
   2. Is its cost proportionate to its usefulness?
   3. Does it need all of its features?
   4. Is there anything better for the intended use?
   5. Can a usable part be made by a lower cost method?
   6. Can a standard product be found which will be usable?
   7. Is it made on proper tooling--considering quantities used?
   8. Do material, reasonable labor, overhead and profit total its cost?
   9. Will another dependable supplier provide it for less?
   10. Is anyone buying it for less?
6. Value News (Figure 7), a weekly single page flyer goes to engineering, manufacturing and purchasing

FIGURE 7

management. A typical issue uses an eyecatching sketch of a magician viewing the two bleeding halves of a freshly sawed woman as the caption says, "They've sawed her in half again." Then follows an illustration of a military package in which our equipment was shipped. This package did cost $26.00 but now we have found a way to do it for $8.50--1/3 of the cost.

7. Another "Informer" is New Materials News. Each month (Figure 8) it is issued to engineering, manufacturing and purchasing people. It contains several pages of one paragraph extracts of what is said to be

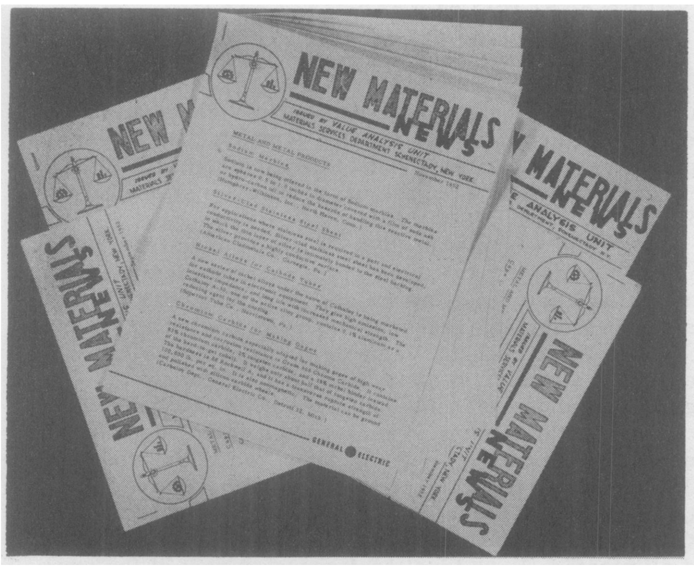

FIGURE 8

new and useful to industrial products. The manufacturer's claims are stated and his name and address are given.

When buyers have learned "function" or "Value" buying, when Value Analysis specialists are trained in Value techniques, when the proper human relations climate has been created, and when the necessary specific information is provided to each, then the job of plant-wide creative cost reduction under purchasing leadership is well on its way.

WHAT ARE THE RESULTS?

Let's look at the parade.

Save Vendor Manufacturing Expenses

A perforated metal sheet (Figure 9) cost $1.75 each. It has thousands of holes, yet special holes are made at the ends for mounting. Wouldn't this same job be accomplished by a continuously perforated sheet using the same holes for mounting? The ends are in mounting straps anyway. Sure enough! The same performance results, and the cost drops from $1.75 to $1.25 - saving $35,000 per year.

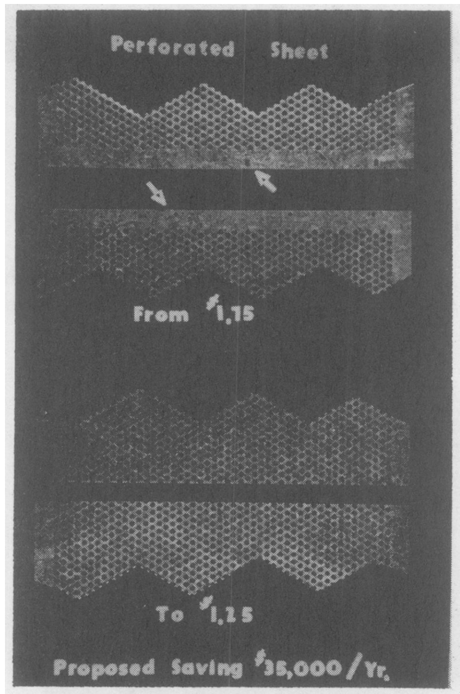

FIGURE 9

Use Available Vendor Standards

Switches cost $.86 each. Material was purchased and stampings were made in the factory. But specialists were found who make standard switch blades and insulation parts for this type of construction and the search disclosed that their parts could be provided for $.16. The same performance for 20% of the cost!

Use Vendors' Special Machines and Skills

Or, (Figure 10) let's consider a cover made as a machined casting costing $1.07. A specialist supplier will provide it as a stamping from heavy steel accomplishing the same performance and cost drops from $1.07 to 57¢, saving $54,000 each year.

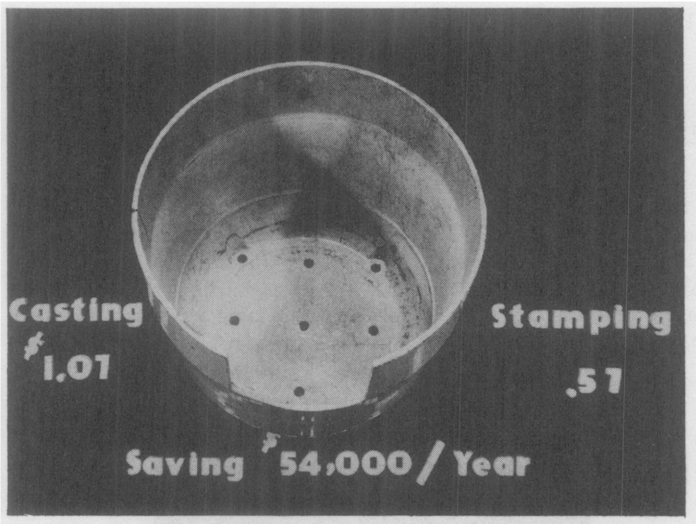

FIGURE 10

Use A Different Form of Raw Material

Or let's study (Figure 11) the valve body which machined from bar costs 17.8¢ but when made as a machined casting costs 5.8¢, saving 60%, $40,000 each year.

FIGURE 11

Use Available Functional Products Instead of Specials

The specially made small metal knob was supplanted by the sturdy plastic knob having metal inserts and pointer and cost dropped from $2.25 each to 25¢. The same performance for 1/9 of the cost.

It Pays Off For High Volume

In the high volume field, millions of very precise stainless steel pins were being purchased for $3.00/M but after Value Analysis studies with the people who made them and with others, changes which did not affect quality were made in the vendor's plant so that much unnecessary expense was eliminated. The result was that the supplier re-quoted a still profitable item at $2.00 instead of $3.00. Saving was near $100,000 a year.

It Pays Off For Low Volume

Small quantities of 3" plugs were being made for $15.00 each. They can be purchased in plumbing shops for $3.00.

It Pays Off For Production Materials

Small terminal boards were traditionally made of small metallic terminals on plastic. Going for help to a maker of special machines, terminal boards of identical performance were made of metallic ribbon automatically assembled to similar plastic, for one-third of the cost.

It Pays Off For Expense Materials

A package cost $.43. Brought to the attention of specialists in the company and outside, a different package which would better stand all of the bump and crush tests was developed. Instead of 43¢ it cost 20¢. Better performance for one-half of the cost! ...Or a shipping carton about a 6" cube complete with fillers which brought four small rugged metal clamps each the size of a pencil eraser. A mailing bag would have done the same job for one-fifth of the cost.

IS VALUE ANALYSIS ALWAYS TOO LATE?

Always when the opportunities of creative Purchasing Value Analysis are shown, there are those who say, "But you're too late--these vendor products, these available specialty materials, these special vendor skills, these engineering modifications should be used right from the start. After tools are bought and production started it is too late!"

Yes--that's true--but they cannot be used from the start! We'd like to have them in the original design, so in Purchasing Value Analysis we do everything possible to assist the design engineers. Of course, the better we try, the better we do, but the Value Analysis yield we have shown here is the yield after the finest we can do in engineering and in manufacturing methods and the best job we can do in Purchasing. Precise engineering decisions cannot be made in short "design time" while the whole field is chance--but after production, with experience, with the flow of physical samples, with time to test each detail separately, unnecessary costs can then be isolated and eliminated. Each functional group or part of the product can then be illuminated by the suggestions of specialists and its value improved by the new processes, materials, and skills of today and tomorrow.

The job of Purchasing Value Analysis is to get today's and tomorrow's materials, ideas, methods, and processes into use today. To accomplish this, Purchasing Value Analysis provides facts--facts with a broad base--facts on which all manner of management decisions will be based. Sometimes the facts will support decisions to buy new machines, sometimes to eliminate non-working material, sometimes to use different suppliers, sometimes to make more and sometimes to buy more. But always, these facts support more function to the user for less cost--always Better Value.

IT GETS BETTER VALUE BY PROMOTING GOOD VENDOR RELATIONS.

Purchasing Value Analysis truly provides to the best vendors... opportunity. Opportunity to sell their ideas and materials where they will be effective.

For example, we quote one:

"I feel that never before has a specialty vendor had so wonderful an opportunity.... "

And another:

"I wish to thank you for the opportunity to participate.."

We summarize... to evaluate is to compare--compare what we have with the best that we could have.

How do we do it now? What does that cost?

How could we do it? What would that cost?

The Purchasing Value Analysis program trains buyers to buy function, and teaches Value techniques to the engineer specialists. They use the Value Analysis Job Plan with its Information, Speculative, Analytical, Program Planning, Program Execution, and Status Summary Phases. These are the "Good Seed."

"Value Analysis" builds the "reaching for help" attitude in these buyers, these specialists and their human environment of engineers, manufacturing men and management. All techniques are carefully selected to build good human relations. This is the "Good Soil."

Then Value Analysis provides action information--idea sheets, Value News, specialty vendor knowledge, and specialist information. This is the "Proper Nourishment."

The Value Analysis program develops men who know what to do. It provides an effective place to do it. Then supplies the tools for the job.

As we conclude, let us review that high cost is an arch enemy. High cost keeps the poor mother in the dish pan and at the scrub pail. High cost sends the expectant mother out in the winter storm to hang the clothes on the line. High cost keeps the nauseating garbage can in the kitchen. Whoever eliminates unnecessary costs puts shoes on the unshod, gives eyes to the half blind, provides strength to the over-tired, adds convenience for the deserving and gives meaning to this era of technology.

THE APPLICATION OF OPERATIONS RESEARCH TO INDUSTRY

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Operations research, or Opsearch as it is often abbreviated, is the new name for an old management technique which appears to be of increasing interest to industrial executives. Many of its older roots are held in common with industrial engineering and, like industrial engineering, its beginnings go deep into antiquity. Its above-ground growth and application were slight and sporadic until World War II when, as an aid to military management, especially in combat operations, it underwent a mushroom like growth.

Today, in addition to the groups doing operations research for the Defense establishments, there are many business, scientific, and educational organizations interested in the field, and in many cases actively contributing to it. The Appendix, which includes organizations engaged in military as well as industrial operations research, gives an idea of the wide interest that now prevails. Further evidence of this growing interest is the organization of the Operations Research Society of America, a professional society of operations analysts, which now has a membership of about 500 and publishes a quarterly journal. It seems evident that operations research has become a profession in its own right.

There is some reason to believe that at the present time the methods of operations research are closer to those of the basic sciences than to engineering. The majority of practitioners of operations research tend to come from the basic sciences rather than from engineering, and they use the attitudes and tools of physics rather than of electrical engineering, of psychology and sociology rather than of personnel management studies. However, the techniques and methodology of operations research do have a great deal in common with the techniques and methodology of industrial engineering and of management consultants.

It is clear that operations research has been concerned from the start with the decision-making system and with the problem of providing individual executives with management advice. It has a role, therefore, similar to that of industrial engineering. Like industrial engineering, it has, on behalf of the executive, been concerned with the development or calculation of future courses of action on the basis of exceedingly detailed knowledge gained from experience. It has differed from industrial engineering in its more conscious and more overt recognition of the need to get specialists, highly skilled in each field of knowledge having bearing on the particular action problem, to work in more closely integrated team research. Opsearch probably has been more systematic in its attempt to develop action models based on fundamental theory, similar to the model-making of the basic sciences, and in its heavy reliance on the more complicated mathematical concepts and techniques. It has, perhaps more than industrial engineering, been conscious of the need to estimate the uncertainties in its predictions when these have been concerned with tactical and strategic action problems, where the parameters are heavily dependent upon human behavior, upon assumptions with respect to competitor intentions, or upon imprecise intelligence knowledge of competitor capabilities.

I believe that a difference in timing is another of the distinguishing characteristics between the kinds of studies made by industrial engineers and management consultants, and those made by operations analysts. An operations research study usually takes a longer time to complete than a study by either one of its predecessors in the field, the tendency being to carry out studies of new courses of action which involve longer-range futures. These seem to be more in the nature of research studies than of engineering.

Operations research places a particular demand on the operations analyst for the ability to translate his findings into executive language -- that is, into language which simply and clearly sets forth the values, effectiveness, and costs of a set of proposed courses of action.

In the remaining sections of this paper I shall give chief attention to outlining methods of operations research, with the hope that this may assist in its further and broader application. I shall discuss four elements of operations research as follows:

- I The Relation of the Operations Analyst to the Executive.
- II The Operations Research Checklist for Solving Action Problems.
- III Some Selected Analytical Tools Used in Operations Research.
- IV Simple Case Histories in Operations Research

I THE RELATION OF THE OPERATIONS ANALYST TO THE EXECUTIVE

Let me remind you here of the nature of the decision-making problem faced by the executive. In Figure 1 I have tried to show diagrammatically the principal activities controlled by the executive of a large organization - including his management, intelligence, and planning actions -- although not, of course, in full detail. This is the usual kind of diagram showing the feed-back loops, or at least some of them.

The first point I would like to make is that applied research occurs at several points in this system. Three different kinds of research are shown in Figure 1. The first is development research -- that is, research concerned with the development of specific machines, or with techniques of training personnel, or with the design of organizations. In general this kind of research is devoted the development of specified end items, in both machine systems and social systems.

The second kind of research is intelligence research. This is of two broad general types. One type, research in auto intelligence, is the study and synthesis of all the information bearing on the organizations own capabilities and performance. This includes studies of productivity, inventory, cost, etc. The second general type of intelligence study deals with information involving the general physical and cultural environment of the action theater; as for example, the buying habits of consumers, response of consumers to sales promotion, transportation systems, natural resource distributions, etc., and also studies of

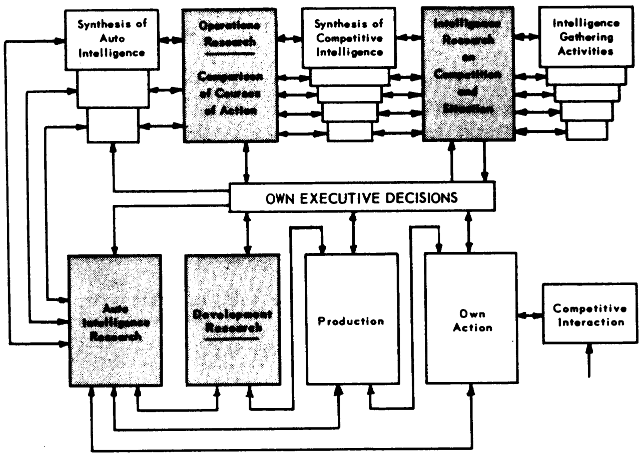

Fig. 1—Relation of Applied Research to Executive Decision

the competitors involved-including all information on competitor capabilities.

The third kind of research is operations research - the comparison of existing courses of action with new proposed courses of action. Research of this type uses as raw material all information bearing on a particular set of proposed actions taken as the research problem. Existing research of this type has been done by industrial engineering and by management consultants. Operations research is entirely concerned with research in this area.

It is important to note one characteristic of these kinds of research to the executive. Most of the thinking that occurs in the organizational brain in the boxes marked "Development Research", "Intelligence Research", and "Operations Research", occurs at the subconscious level so far as the executive himself is concerned. That is to say, he sends down a question and at some later time he gets an answer, but meanwhile he doesn't usually follow continuously the resulting studies.

It is clear from the other loops I have shown in the organizational diagram that often the executive may and does act on direct information supplied him by his action agencies.

The executive is in a position to ask questions at any level of the organization. Whenever he asks operations research a question, he must define the area and limitations of the problem that he wants to have considered. At times however, operations research, like a part of a good and creative brain, will come up with an answer to a question that has never been asked but that has become self-evident because of the continuous correlation of data stored in the memory banks (if the individuals doing the operations research are at all creative).

In Figure 2 I have shown the general interaction of operations research with the three main organizational levels at which it may be carried out. Figure 1 was primarily the kind of diagram for operations research concerned with strategic courses of action - that is to say, with the main courses of action of a very large organization. However, operations research can occur at any level down to and including that of the individual. For large industries, a rather broad categorization can be made at three levels. The lowest level is the technological level where operations research is concerned with the comparisons of different end products -- of machines, including their costs, or production line design, training procedures, etc. Usually the technological ends are derived from the tactical requirements although, as the diagram illustrates, they may sometimes stem from strategic requirements or interaction with competitors.

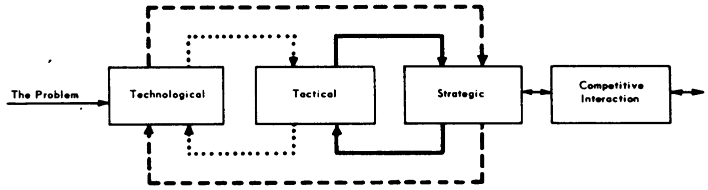

Fig. 2—Interaction between Action Levels

In Figure 3, I have illustrated the interactions among operations research, the planning function, and the three main sources of data. The technological factors and the human factors involved in an operations research study come primarily from the basic, applied, or engineering sciences. The systems factors come either from passive observation and analysis of past or present operating systems -- one's own or competing systems -- or from deliberately designed operational experiments in which the existing organization interacts with its consumers or competitors.

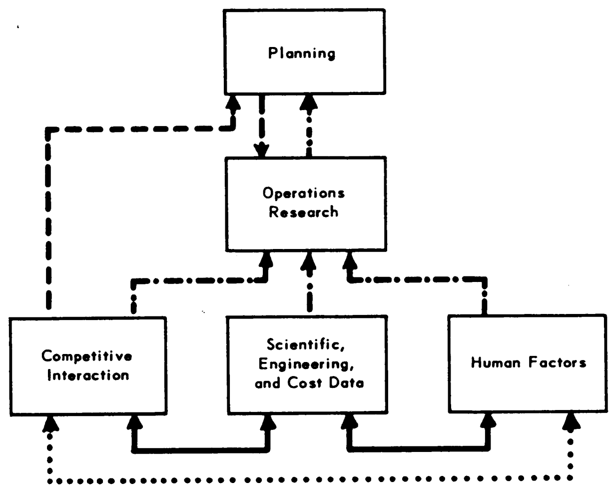

Fig. 3—Interaction between Action Parameters

At the intermediate level, the tactical level, the primary concern is with alternate ways of using existing or future technological means to achieve the strategic requirements of the organization. Such studies might be concerned with different kinds of sales promotion, with alternative production methods in a broad sense, with the location of alternative specific merchandising outlets or of factories, with manufacture of a new product, etc. The tactical ends are usually established by the strategic requirements and by the assumptions on which initiation of studies are based. As in the case of the technological studies, the tactical studies may be influenced by feed-back from technological, strategic, or competitor interactions.

The top, or strategic, level for operations research will be concerned primarily with the main broad courses of action of the organization. For example, should the organization operate on a stable, long-range, low-profit basis or on a high-profit, short-range, unstable market basis? Although strategic operations research is modified by interactions with the technological, tactical, and competitor actions, in general its ends will be specified by the executive on the basis of organizational policy.

II THE OPERATIONS RESEARCH CHECKLIST FOR SOLVING ACTION PROBLEMS

I want next to introduce you to the operations research checklist. This is shown in the two following tables.

Operations Research Checklist - The Formulation of the Problem and Preliminary Decision

1. Study of Result to be accomplished
2. Relative Competitive Strength
3. Appraisal of the Importance of Problem
4. Preliminary Determination of Courses of Action
5. Competitor Courses of Action
6. Selection of the Best Course of Action
7. The Preliminary Decision

Operations Research Checklist - Calculation of the Problem

8. Assumptions
9. Alternate Plans
10. Determination of Operations
11. Organization of Tasks and Forces
12. Assembly of Measures for Freedom of Action
13. Assembly of Information
14. Preparation of Subsidiary Plans
15. The Final Decision

As you will easily recognize, this is a simple, brief statement of Aristotle's method for solving problems and has been adapted from the Military Estimate of the Situation. It is essentially a checklist for a scientific or engineering step-wise procedure for solving industrial problems which has been found very useful in operations research. The first table shows the steps that need to be taken in order to arrive at a preliminary decision. In a brief outline of these steps you will recognize the use made of information coming from developmental and intelligence research as well as from systems information.

ESTIMATE OF THE COMPETITIVE SITUATION

I. ESTABLISHMENT OF THE BASIS FOR SOLUTION OF THE PROBLEM

A. Study of the result to be accomplished.

(1) Summary of the Situation

This is a statement of known information which will serve as a background for visualizing the problem. Broad disposition of the organizational units, the progress of the industry, and orders received may be included. Details should not be included; these come later. Don't draw deductions. This section merely presents a broad picture of the action situation.

(2) Recognition of the Incentive

Will be one of the following:

(a) Orders from higher authority.
(b) Previous decision creating new problems.
(c) Demands of the situation.

(3) Appreciation of the End to Be Attained.

Here, break down assigned action into a statement of the result desired. Be sure you understand the immediate purpose of the job which has been assigned to you or which you have determined for yourself. See how this fits into the general plan of your superior, either by analysis or directives, or by deductions. If possible, deduce the results which he is trying to attain. Clarify in your own mind the "Chain of Objectives".

(4) Statement of the Problem

Based on the foregoing sections, state accurately and briefly the job you have to do, and the reason why it is to be done, i.e., your "Task" and "Purpose." Normally the Purpose would be to assist in carrying out the general plan of your superior.

Examples:

(Task) - Initiate intensive sales promotion campaign in Midwest.

(Purpose) - To counter success of Company B in capturing market in this area.

(Task) - Redesign product A for manufacture at lower cost.

(Purpose) - To change present loss on this product to a profit.

B. Relative Competitive Strength

(1) Means available.

(a) Products and their characteristics.
(b) Distribution means and their capabilities
(c) Personnel
(d) Sales Organization
(e) Logistics: material, personnel, and facilities.

(2) Characteristics of the environment

(a) Topography
(b) Hydrography
(c) Weather
(d) Cultural habits affecting business
(e) Relative location and distance
(f) Lines of transportation and supply; competitor traffic
(g) Facilities, location of raw materials
(h) Communications

(3) Means opposed

(a) Competitor distribution system and products: sales organization
(b) Personnel
(c) Material
(d) Logistics: facilities

(4) Conclusions as to relative strength of competitor.

Here are listed deductions based on the facts collected in the preceeding three subsections. A good form is to list one's own strength and weakness factors in a column parallel to those of the competitor. Note that one's own strength does not necessarily mean a corresponding competitor weakness.

C. Appraisal of the Importance of the Problem

Since every industrial endeavor involves some measure of risk, it is necessary to have an idea of the importance of the task in order to decide whether its execution is worth while. Some tasks are so important that they require an all out effort, regardless of consequences; others are less vital and should not be carried out if the risk is great. To form a basis for such evaluation later in the estimate, in this section assess as best you can the importance of the mission.

II PRELIMINARY DETERMINATION OF COURSES OF ACTION

A. Re-examination of the Problem

Though you have already analyzed your objective, the study of relative competitor strength and characteristics of the environment may lead to the conclusion that your problem should be revised. This is particularly true in cases where the incentive arises from your own previous decision or from the demands of the situation. However, do not be misled into considering here how you are going to do your job; this subsection is devoted to a critical re-examination of what the job is and the further purpose to be served.

End with a restatement of the mission.

B. Survey of Courses of Action

Here, list possible ways to accomplish your objective. This is to be done in broad terms, not by listing detailed operations. Make them very general, in order to cover all possibilities. For example, if the Task is "to maximize long range profit..", possible courses of action might be:

(1) To capture a moderate but stable part of the market.
(2) To use sales promotion to establish long range prestige of the trade name.
(3) To eliminate dangerous competitors by underselling.

It is not necessary -- it may even be undesirable -- to specify in this section the type of production process, sales promotion, or product to be used. It is clearly wrong to list detailed operations. Try to visualize in very general terms all the different ways by which you can accomplish the job you've been given, and set them down. Eliminate only the fantastic ones; don't yet mentally reject any possibility, even though you doubt that it will work. Sometimes only one course will occur to you; rarely will you have more than four or five. If you think of more than a half dozen, then you are really thinking of detailed operations, not comprehensive courses of action. Start again, and set down only general plans for accomplishing the objective.

C. Testing Courses of Action

Now take each course of action in turn and subject it to the three tests listed below, using as a basis the material accumulated in sub-sections A, B, and C respectively of Section I. Design physical and mathematical models of action and use analytical operations research tools to quantify effectiveness, costs, and values.

(1) Suitability
  (a) Is the course of action appropriate to accomplishment of the objective?
  (b) Does it completely accomplish the objective? If not, does it assist in its accomplishment?
  (c) Does it accomplish the objective within the period of time necessary to achieve the purpose of the problem?

Quantitative results measuring effectiveness from the model are very important here.

(2) Feasibility
  (a) Is it possible to carry out the operations contemplated, with the facilities available, against expected competitor opposition, and in the theater of operations ?
  (b) How easy is the operation to carry out?
  (c) Does the course utilize one's own strengths and capitalize upon competitor weakness? This is generally given by model costing.
(3) Acceptability
  (a) What are the consequences as to costs of the course of action?
  (b) Are the costs acceptable in the event of failure?
  (c) Are the costs acceptable in view of the importance of the problem?

The operations research theory of value is especially important here.

D. Listing Retained Courses of Action

The foregoing tests may cause rejection of one or more courses. List the ones you have retained as possibilities. You may here wish to combine two or more courses which alone are unsuitable or infeasible but which in combination meet the required tests. Here use symbolic logic.

III COMPETITOR CAPABILITIES.

A. Survey of Competitors Problem

(1) Summary of the competitor's situation.

Put yourself in the competitor's shoes. In what sort of situation does he find himself? What problem confronts him?

(2) Analysis of the competitor's objectives.

What result does the competitor desire to bring about? You probably won't be able to deduce his exact problem, but you should have some idea of what his general objective is.

B. Survey of Competitor Capabilities

On the basis of the foregoing survey - the list of competitor's means - what are the capabilities which might affect your courses of action? Do not omit any possibility just because it is unlikely. List here all competitor capabilities; don't restrict yourself to competitor intentions.

C. Test of Competitor Capabilites.

Now apply to possible competitor courses of action the same three tests you used for your own courses of action. Since your information about the competitor is meager, don't be too hasty in eliminating any capability; discard only those which clearly fail to meet the tests.

D. Listing Retained Competitor Capabilities.

IV SELECTION OF THE BEST COURSE OF ACTION

A. Comparison of Retained Courses

Execute, in theory, each of your own courses against each competitor capability. This involves breaking down the course of action into more detailed operations to see how it works out. Re-estimate the competitor's situation if necessary. Make further combinations of your own courses if it seems best. By this process you may or may not decide now to reject one or more of your courses.

B. Determination of the Best Course

The foregoing analysis should enable you here to compare the courses you have still retained. A tabulation of their advantages and disadvantages may be helpful in picking the best. If you have decided on a combination of two or more courses, be sure to test the combination for suitability, feasibility, and acceptability. Again use action models and analytical operations research techniques in comparison. Here use symbolic logic.

V THE PRELIMINARY DECISION

State your best course of action as your decision. Couple with it the purpose of the decision, which is the motivating task.

List any corollaries to the decision which your analysis has developed; that is, any subordinate deductions arrived at which limit the scope of the decision or affect the manner in which it is to be carried out.

PLANNING DETAILED OPERATIONS

Items 8 to 15 of the operations research checklist show the steps necessary in planning the detailed operations leading to a final presentation of the alternative possibilities for organizational improvement. Again, the information comes from the same source as were discussed previously. The steps are outlined briefly in the following paragraphs.

I. ASSUMPTIONS

In the "Estimate" you decided upon a basic plan. This decision was based upon the best, but probably incomplete, information available. Now determine what conditions must exist if the plan is to be successful. Don't list possibilities or expectations; only list the assumptions on which your plan is based - that is, the facts or conditions which may or may not exist but which must exist if your plan is to be successful.

For example, if the decision were "to eliminate competitor A by underselling him", a proper assumption might be: Competitor A does not have the necessary capital to survive price competition for more than six months. On the other hand, the statement: Competitor A will meet the price competition is not an assumption. Both statements are expressions of what opposition is anticipated; both may or may not be true; but the first one is a condition which must be true if the plan is to be successfully carried out, while the second need not be. An assumption then, as used herein, is a statement of a condition whose existence is essential to the successful execution of the plan. If, however, you are preparing an order not a plan, then assumptions have no place. An operational plan is to be carried out only if the assumptions stated in it are actually true; an operational order is to be carried out (subject to the usual exceptions) without qualifications.

II. ALTERNATIVE PLANS

It may be desirable to devise two or more plans based on different assumptions or sets of assumptions. A typical example of alternative plans would be Plan A based on the assumption that an inflationary economy will exist and Plan B based on the assumption that a deflationary economy will exist.

III. DETERMINATION OF OPERATIONS

There are many ways of determining detailed operations. The one here suggested will tend to prevent omitting an essential element. Any successful industrial operation has the following constituent characteristics:

Effective action with relation to correct physical objectives; projection of action from advantageous relative positions; proper apportionment of competitive strength; and ensurance of adequate freedom of action.

Knowing the result that you wish to obtain (the decision arrived at in the estimate), break it down into the following elements.

A. Effective Action with Relation to Correct Physical Objectives

(1) What are the correct physical objectives? they may be industrial locations; sales areas technical personnel, ships, or other transport means; development laboratories or factories.

(2) What action with respect to these objectives will assist in carrying out the plan?

(3) Consider the possibilities of concealing from your competitor (e.g., by feints) what your ultimate physical objective is.

B. Advantageous Relative Position

From what geographical locations can the contemplated action be projected? Is a change in position or a movement of facilities necessary? Here consider time and space factors.

C. Measures for Freedom of Action

(a) Provisions for exercise of authority, including communications.
(b) Effective training
(c) Security measures
(d) Intelligence and counter-intelligence
(e) Morale
(f) Plans for surprise, if desirable
(g) Plans for retaining the initiative
(h) Logistics support
(i) Measures for cooperation

This list is not all-inclusive

D. Apportionment of Competitive Strength

(1) Consider own strength and weakness factors Determine whether to oppose own strength to competitor strength, and dispose of his strong points first, or whether it is better to attack first where he is weak.

(2) Consider strategic as well as tactical considerations.

(3) Allocate adequate organizational units to each operation, from the point of view of suitability, feasibility, and acceptability.

Now is an appropriate time to test each operation for suitability, feasibility, and acceptability Make further breakdowns or combinations; discard operations or measures which do not meet the tests; list or check those retained. Again use action models.

IV. ORGANIZATION OF TASKS AND FORCES

In the foregoing section, the decision was broken down into detailed operations, and the forces available were apportioned. These detailed operations should have been stated in terms of objectives; For example, under consideration of measures for freedom of action, it might have been decided "to avoid disclosing prematurely the sales promotion compaign". Stated in terms of tasks, this becomes: "Avoid premature approach to advertising outlets". Frequently, operations can be rephrased as tasks merely by removing the preposition "to".

These tasks must be grouped according to the units which will carry them out, and the units themselves will usually have to be broken down into sub-units performing the same or similar tasks. No rule-of-thumb is possible; Too great subdivision usually complicates the allocation of authority, whereas combining too many units in one group will tend to make effective control more difficult.

Some tasks will be applicable to all units; these are grouped in one place to avoid repetition.

Complete the organization by noting the executive for each group of units.

You will now have a list of groups of units with the tasks that each performs. These must be tested, from the point of view of the subordinate executive who is to carry them out, for suitability, feasibility and acceptability. This step is very important. It is not a repetition of previous tests, but the final analysis after the specific forces have been assigned to specific jobs.

V. ASSEMBLY OF MEASURES FOR FREEDOM OF ACTION.

(a) Measures required for security, for cooperation, and for intelligence activities.

(b) Measures for logistics support. These cover provisions for procurement and replenishment of supplies, disposition and replacement of ineffective personnel, satisfactory material maintenance, and the like.

(c) Measures for the exercise of authority. These include provision for communications, location of operating areas, and the location of the executive.

VI. ASSEMBLY OF INFORMATION

It is necessary to transmit to subordinates all the information required by them to do their jobs properly. Here is the appropriate place to note what items should be furnished them.

VII. PREPARATION OF SUBSIDIARY PLANS

Either the estimate itself or the determination of detailed operations may have created subsidiary problems. For example, it may be necessary to prepare training plans, intelligence plans, or, in the field of operations proper, production schedules, detailed sales plans, etc.

These problems lend themselves to the same treatment as that given the basic plans, just discussed.

VIII CONCLUSIONS AND RECOMMENDATIONS

On the basis of the preceding studies, announce your conclusions and recommendations. Include in your conclusions the estimates of effectiveness and costs of solving the problem, and the value to the company.

In figure 4, which bears on this problem, I have shown diagrammatically the way in which the executive will use this kind of information.

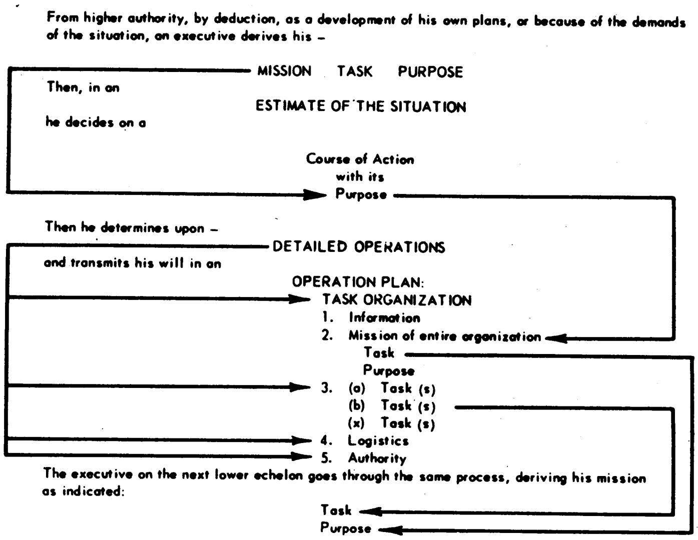

Fig. 4—The Chain of Objectives

III SOME SELECTED ANALYTICAL TOOLS USED IN OPERATIONS RESEARCH

Having outlined the operations research checklist, I want to discuss briefly the techniques that have been most useful in operations research. They are listed in the following table. None of these will be exactly new to you, but in operations research model-deseription they have been found to be especially applicable.

Some Important Analytical Tools of Opsearch

1. Probability and Statistics
2. Symbolic Logic
3. Theory of Value
4. Queing Theory
5. Stochastic Processes: The Monte Carlo Method
6. Suboptimization
7. Theory of Games

PROBABILITY AND STATISTICS

First of all, very broad and extensive use is made of probability and statistical analysis. Since this is so well outlined by Kimball and Morse in their book and is such a generally used tool in industrial engineering, I will not describe the particular mutations used in operations research.

SYMBOLIC LOGIC IN OPERATIONS RESEARCH

As a preparatory step in arriving at any decision, the consequences of possible choices, as well as the relationships among known data, are examined. In certain simple cases the meanings of the facts are well known, and the results of possible choices are predictable. When decisions involving complexly related data are required, opsearch vision can become dimmed as a result of failure to interpret as fully as possible the many component elements in a situation. It is frequently the case that an operations analyst does not have enough facts to support an important choice, and it is perhaps more frequently true that the implications of the facts which are available have been only imperfectly recognized

Statements about facts can be symbolized by single letters, and separate statements can be connected by a symbol which represents the relating word between them. Such relational words are and, or, if, then, neither, etc. When several statements are interconnected by appropriate relational symbols, complex situations can be concisely expressed. The pattern set up among these symbols immediately discloses situations which do not fit into the pattern — cases which are inconsistent with the statements. We have a sort of symbolic picture which might easily be worth ten thousand words.

Symbolic logic is the tool which can be used for the analysis of a pattern so designated. It may be looked upon as a sort of generalized mathematics, dealing with statements instead of numbers. It defines the manipulations and transformations which are logically permissible. Symbolic logic will, then, operate to indicate what inferences can reasonably be drawn from described situations, and what inferences are false.

An example drawn from a production engineering problem will serve to illustrate one application of this tool for valid reasoning.

For some years a manufacturer has been producing a mechanism composed of three intermeshed parts. Recent researches into the properties of metals, however, have disclosed the possibility of producing a better product, and for less unit cost. In the case at hand, six different metals might have been used for one of the three parts, five might have been used for another, and three might have been used for the third. There was, therefore, the mathematical possibility that 90 new mechanisms would need to be compared with the old mechanism in order to be certain that all cases had been considered. Research and development efforts are expensive in both time and money, and a means was sought to reduce the number of new combinations which should be investigated.

The engineering department prepared a list of specifications, reading about as follows: (1) If metal A is used in the first component, then metals D and E should not be used in the second, and metal J should not be used in the third. (Presumably these restrictions were imposed because of discovered frictional and electrical properties which could not be tolerated.) (2) If metal B is used in component one, then metals D and E should not be used in component two, and metal H should not be used in component three. The full list of restrictions would have been the delight of a Sunday Puzzle worker. A second list, describing the expected performance characteristics of the components was also drawn up. It may be observed that 28 statements were prepared describing in full the known properties of the components. By implication, these were also known facts about the 90 possible cases under surveillance.

The cost accounting department calculated the relation ship between the costs of the materials and the old, and estimated the cost of converting the new production methods. Armed with these additional estimates, and with a policy decision outlining permissible cost levels, the analyst had enough facts at his disposal to prepare a positive recommendation as to which of the 90 possible combinations should be examined further.

It is of interest to note that, in this case, the problem was solved by the use of symbolic logic. Engineering specifications eliminated 73 of the combinations, and cost engineering specifications reduced the list by an additional 15.The remaining two combinations were, therefore, the onlt two cases consistent with all the demands of the manufacturer.

Once the facts were available, symbolic rules in this case could be listed, and the results obtained, in less than an hour. High speed computers could have solved the problem in several seconds. In this case, however, there were not enough complications to warrant the use of a computer, since the problem could be solved by hand in a matter of minutes.

THE THEORY OF VALUE WITH RESPECT TO INDUST - RIAL OPERATIONS RESEARCH

It is pertinent to describe in brief the development of the Theory of Value, or worth, or importance, as you may prefer to call it, with respect to military operations research, and to make some speculation concerning its development with respect to industrial operations analysis. Decision is based on two types of considerations: consideration of probability -- that is, the probability of the occurence of various possible outcomes - and considerations of the worth, or value, of these outcomes to the executive. The product of probability and value summed over all possible outcomes is the expected value, or simply the expectation with respect to the given course of procedure.

The problem of elementary decision is to ascertain the course of action of greatest expectation and, of course, the indicated choice is this particular course of action.

We now can give a more concise and a more all-embracing definition of operations research as simply "the science of decision". What remains, then, for the executive to do? Analysis will show that the values of intermediate states in the military system depend ultimately on the probability of winning or losing the war; that is, on the value of certain states which end the fight, which we call trapped states. The absolute evaluation of these outcomes is arbitrary and must be stated axiomatically. For this reason, if for no other, the science of decision can never replace the executive who is involved in all aspects of decision, whether probabilistic, deterministic, intuitive or axiomatic. It should be as much the function of the operations analyst to aid the executive in the estimation of values, based upon his particular set of axioms, as in the estimation of probabilities.

All of the currently used, and at present vaguely defined words peculiar to operations research can now be given precise operational definitions in terms of the value concept. Such a word as "Effectiveness" of a system is revealed to mean the change-in-state value brought about by the use of the system. The latter can be broken down into enemy value destroyed and friendly value consumed. The friendly value consumed may or may not be the cost of the system, but must include the values of the intrinsically valuable quantities consumed.

Another aspect of decision that deserves attention is the element of conflict. Conflict in decision is the rule rather than the exception. Conflict occurs whenever the individual making the decision exists simultaneously in several systems -- his self system, family, business, lodge, church, and nation systems, for instance. He will frequently arrive at a point where a particular course of action will increase the expectation in one of his systems and decrease it in another. Conflict as thus described frequently occurs between the self-system and the group-system, for instance. How are these resolved? (1) By repression or sublimation; for instance, the relative value of the self-system can be devaluated and considered small with respect to the group and thus allow decisions in favor of the group; or (2) by an appeal to the set of super values and constraints imposed by the government; that is, an appeal to law; or (3) by appeal to a set of super values which are not officially held and which may be written or unwritten, but are those included in the moral or ethical standards of our culture; or (4), and most importantly, by the enlargement of the system considered to include all the conflicting systems as subelements. To establish a single set of scaler values in this new enlarged system may require the establishment of new fundamental axioms which in themselves may be crystallizations of formerly accepted super values. For instance, in resolving the conflict between the thirteen original states the coalition of states (the United States of America) required a set of axioms (the Constitution) the writers of which were guided by a new axiom of government, and I quote: "We hold these truths to be self-evident -- that all men are created equal..." and so on. This general method of resolution of conflict by the enlargement of the system of attention, together with the readjustment of the axiomatic structure, is the fundamental operation of the rational process, whether it involves the making of decisions, the establishment of new policy, or the formulation of new physical theory.

The goal of this process is the ability to rank all states of all systems by preference; that is, to establish a scaler set of values rather than to have separate values that depend on money, values that depend on morals, values that depend on ethics, and values that depend upon religion -- all mutually exclusive. One can consider the set of facts making up our body of knowledge either as a separate set of unrelated points and simply catalog them, or preferably one can establish a system of axioms on the basis of which the entire set of facts may be regenerated by direct operational means. The establishment of values is such a process, and one assumes axiomatically that this is a desirable process.

Thus a new facet to the function of operations research is revealed, and in this sense operations analysis is one of the most fundamental of all sciences in that it is concerned not only with the content of the sciences but with their rational basis of axioms as well.

The Theory of Value can be expected to have far-reaching effects on industrial operations research (or any operations research, for that matter) in that first, it establishes a complete rationale for that science, and second, it gives meaningful operational definitions to its concepts.

The Theory of Value has not yet been extended to a single unified system composed of many sub-systems, such as is represented by a society during peacetime. It is to be expected that operations research in industry is intriniscally more difficult than operations research in the military. In the latter, one deals with a comparatively simple "two individual" system; that is, the values with respect to the desire to win dominate all the factional values involved. This is not true in an industrial case, nor is it true that the ultimate monistic values can be set easily. They are a function of the culture, the ethics, and the political and social theory of our nation. Thus the Theory of Value pertains to society at large and can be expected to embrace parts or all of the economic, social, cultural, anthropological, political, and managerial sciences.

Values on which industrial decisions are based are not always determined by the profit and loss motif. One must not only pay his stockholders well but must also pay his workers well while maintaining a secure and stable company. One is constrained to operate within certain fixed conditions imposed by law, and is judged externally by values based on fundamental axioms of the rights of individuals and corporations and of the nation as a whole. The wealth of an industry is in a certain sense shared by every individual of the nation in that all may utilize the services of that industry. A clarification of these shared values and their weight in industrial decision will, it is hoped, be contributed by the Theory of Value.

While I have not given examples of any precise application of value theory to industrial operations research, and have dealt much of the time in generalities, I have outlined a broad field of fundamental research in operations analysis from which it is expected useful results will be obtained. This expectation is reinforced by experience in military operations research where value theory is guiding methodology in a comparison of complex and combined weapons system, and is giving means by which to carry out operations analysis with due respect for the intrinsic values of human lives and of strategic material.

QUEUEING THEORY

Queueing theory is a recent development that has application to operational systems of the following characteristics:

a) Some sort of units which must be serviced, such as customers in a shop;
b) service which must be performed on them, which may or may not be independent of the number and type of customer;
c) some arrival time distribution for the "customers"- usually a random or partly periodic distribution;
d) and lastly some exit procedure by which the units leave the service point.

The theory is applicable to those cases in which a waiting line or "Queue" of customers begins to form. Sometimes the queue is just what one would expect to find -- a line of people waiting for bus or cafeteria service -- but just as frequently no such physical line is obvious. As an example of the latter situation, a waiter's customers in a large restaurant are distributed physically, but form a queue from his standpoint although the service sometimes seems random to us. Less frivolous examples with obvious queues are:

a) Ore boats arriving at an unloading point;
b) parts standing on an assembly line when all has not gone well in some other section of a factory;
c) and scheduled or non-scheduled aircraft arrivals during foul weather or during large military operations.

Some more subtle queues are:

a) Requests for service by telephone customers or a doctor's patients;
b) transportation difficulties with unscheduled trains or overloaded facilities;
c) and payment of claims by an insurance company during a disaster.

In many cases the answers to the problems are obvious. When the demands of the queue members for service greatly exceed the capacity of the system, over-saturation is sure to occur, while if the demands are well below the service capacity, no problem exists. Unfortunately, for economic reasons most systems are designed to fall between these extremes, and it is in this region between complete saturation and underuse that queueing theory applies. Just how delicate the balance between these two cases is may be shown by an example provided by D. V. Lindley, of Cambridge University. Suppose a service can handle exactly 10 customers per hour and that an average of 10 per hour arrive, but at random times. Eventually a queue will be established, subsequent to which the probability of a customer's having to wait approaches 1 and the mean waiting time becomes infinity. Further, if a slight increase in the service time is caused by the confusion arising from the length of the queue, then saturation occurs at a much lower value. On the other hand, if the arrival rate is decreased to eight customers per hour, then the probability of having to wait is only 3/5 and the mean waiting time is reduced from infinity to 4.9 minutes.

Many more complicated problems occur, not all of which are presently solvable. An important example is that of aircraft approaching a taxiway from lanes around hangers. In such networks with many loops there is a positive feed-back mechanism that causes delay to be amplified, so that situations arise which, though far from producing real saturation of facilities do result in multiply-connected queues, and disaster as far as scheduling goes. Trial and error techniques will sometimes give an answer to such problems but mathematical techniques must be developed for the more important ones.

From an operations research standpoint, the answer is, usually, not to provide more equipment to avoid saturations conditions, but to study the behavior and organization of queues (this is Marshalling Theory) and to use facilities to the best advantage in defeating queue formation. Because of the precarious, unstable nature of queues, small changes in the organization of facilities may result in savings in service equipment, but the even greater savings in the time of the serviced units will greatly outweigh these. Mathematically, queueing theory draws heavily on probability theory, statistics and analysis. The presently insoluble problems may well be approached through game theory techniques, with the result that large scale calculating machinery will be used. A large effort on these problems is justified because it is in complex systems that queues are most likely to appear, where they are most disastrous, and where their avoidance would result in the largest payoff.

STOCHASTIC PROCESSES: THE MONTE CARLO METHOD

It is not surprising that many of the powerful mathematical methods of the physical sciences can be used in operations research when one considers the similarity of the problem -- generating systems. A case in point is the Monte Carlo method, which has become increasingly important since the advent of large-scale calculating machinery. As the name implies, the method makes use of large tables of random numbers, of the type that certain gaming devices are supposed to generate. This is just one of a group of calculational techniques called "stochastic" processes, because of their use of random numbers. The term Monte Carlo is, however, sometimes used to describe the whole class.

The Monte Carlo method itself consists of substituting a stochastic (or probabilistic) procedure for another mathematical (usually analytic) model of the system. The merit of the method lies in its applicability to those cases which require a numerical answer difficult to obtain analytically. The usual problem is to find a stochastic process that has a distribution function (or the probabilities involved in the choices) which corresponds to the physical problem. Once the process is found it should (and usually does) consist of a set of very simple calculations that must be performed many items. For instance, one can consider a mobile particle in a field of stationary ones. The particle takes a velocity and direction determined by a random number and eventually meets another particle. It may be captured or have an elastic collision in accordance with certain fixed probabilities. Its fate is again determined by a random number. This is an ideal situation for a large calculator, with which a large number of runs can be made quickly. Probability theory, in the form of the law of large numbers, tells us that the physical result is approached more and more closely as more runs are made.

Examples of simple, yet valuable, Monte Carlo processes are not hard to find. One such is the ruin problem of a gambler, which has an analogue in atomic pile theory. The analytical formulation is not difficult, but numerical results are not easily obtainable from it. It is considerably simpler and less expensive to play the actual game by machine many times to obtain the distribution of ruin plays. Many physical problems can be expressed as a game in which repeated play is the best recourse in finding the outcome.

An important quality of the method is that a stochastic formulation is frequently very nearly like the physical situation. To be more specific, problems that involve numbers of individual particles, such as showers in electron multipliers or neutron ages in media, are frequently formulated in terms of continuous variables. By the Monte Carlo approach, however, a representative sample of particles is followed through its history and the final distribution found. Some variables which are hidden by their implicit appearance in the continuous case are easily found in the stochastic process and their effects studied.

Monte Carlo Techniques are not limited to problems of the game type. The tedious but common process of the solution of simultaneous equations can be approached by the method, as can the partial differential equations of heat flow and electromagnetic theory. Fortunately, the actual calculation in most cases is quite simple, but the role of the automatic calculator is important because of the great bulk of work.

The Monte Carlo technique appears to be applicable to problems such as sales campaigns, traffic handling problems at seaports and airports, in communication, in scheduling, and in the design of sales and production experiments.

THEORY OF GAMES

The theory of games is a relatively new branch of applied mathematics. It deals with situations in which each of several people can partially influence the outcome of a certain event, but no one of them alone can determine the outcome completely. Each acts so as to influence the outcome according to his preference.

The theory was originally developed to provide a mathematical basis for economics. More recently it has been applied to problems in sociology and in military tactics.

A considerable body of theory has been developed for zero-sum, two-person games -- zero-sum in the sense that no wealth is created or destroyed, but only transferred among the contestants.

One of the simplest games of this type is the game of matching pennies. The whole point of this game is to outguess one's adversary. Neither player can adopt a fixed pattern of calling heads or tails, for if he did, his opponent could anticipate this pattern and call his coins accordingly. However, by calling his coins at random, either player can insure that he will not suffer a net loss in the long run. Thus the game is solved in the sense that an optimum strategy is given for each player, and the expected outcome is determined if each player employs his optimum strategy.

A central theorem in the theory of games is von Neumann's "minimax theorem". This theorem states that every finite zero-sum, two-person game has optimum strategies for the two players and a unique expected outcome for these strategies.

Optimum strategies have been worked out for quite a number of particular games. Also, several general procedures have been devised which will theoretically yield the optimum strategies for any finite zero-sum, two-person game. However, for a game with many choices, the amount of work involved in applying these procedures is prohibitive. Chess is an example of such a game.

The theory of non-zero-sum games is not in nearly so satisfactory a state. Yet it is very important, since it applies to economic processes in which wealth is created, and to military processes in which wealth is destroyed.

Also, there is as yet no well established theory for multiple-person games, although studies have been made of the conditions under which alliances and coalitions are formed.

The theory of zero-sum, two-person games can at present be useful to the operations analyst. The theory of more general types of games needs further development.

Before leaving the problem of techniques, I want to illustrate (see Figure 5) and discuss the three main regions in which most models appear to fall. Although usually constructed for only one region, a model may at times encompass all three regions.

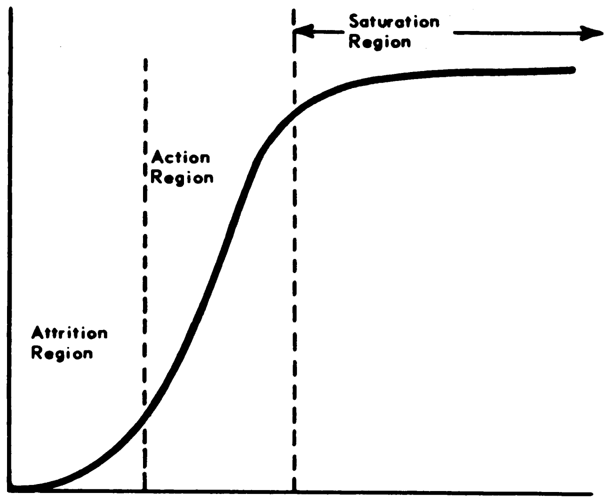

Fig. 5—The Three Areas of Opsearch

The first is the attrition or linear region, in which linear models may be very readily employed. This, of course, is the easiest region in which to construct models. The second is the action region, which although non-linear, may sometimes be approximated by a linear model. The third is the saturation region, which is completely non-linear, and is the most difficult to handle.

A simple wartime example, illustrating the importance of these three regions, is found in the situation of ship repair in Japan as a result of submarine and mine attacks. Japan had limited repair facilities, and when the number of damaged Japanese ships was small, damage to ships had only small detrimental effect on shipping because of the high repair capacity, and counted for little. This was in the attrition region. When the damage began to be much more extensive, in the action region, the effect on Japanese shipping capabilities became marked as queues formed waiting for repair. In this region a damaged ship went from a value of 0.1 to 0.4 of a kill. With a high increase in the number of damaged ships and with repair facilities completely saturated, very long waiting queues formed and a damaged ship became the equivalent of a killed ship.

Another example is the effect of fatigue and fear on the individual in combat, where the human factor must be considered as a nonlinear problem. It is well known that there is a relation between fatigue and fear. Fatigue can be caused not only by physical work but by emotional work. Thus, a man who is afraid will become fatigued and as he becomes more fatigued he becomes more easily afraid.

This can become cumulative and disastrous. If the battle is light and the individual is in good physical condition, he can endure battle for a long time. As his physical exertion and the danger in battle becomes greater, his endurance decreases sharply in the active region. A most exhausting situation in the saturation region occurred in the landings at Normandy, where the waiting was long under very heavy and determined German attack. The fear engendered by the situation was so intense that it brought on extreme physical fatigue, so great that many men drowned in a surf that ordinarily would not have been at all dangerous. There are many other examples of social behavior of this type which occur in industry.

IV OPERATIONS RESEARCH CASE HISTORIES

SEA MINING AGAINST JAPAN

Next, as illustrations, I want to give you the results of several operations research studies. The first one is taken from my own experience in the Pacific in the use of sea mines against Japanese shipping. This particular campaign was conducted entirely on the basis of findings derived in operations research studies.

The first studies were made at the technological level at the Ordnance Laboratory in the Washington Navy Yard. They had been preceded by primitive strategic and tactical opsearch studies. The weapon studies were concerned with the comparison of simple versus combination influence-mine mechanisms, contrasting their ability to withstand enemy minesweeping and their effectiveness in sinking enemy ships, at various depths of enemy water. The target widths and sweep-proofness, for example, of magnetic versus pressure influence mines were compared, as well as such problems as the need for flexibility in meeting enemy technological improvements during the course of the mining campaign. These analyses, as an aid to developmental research, resulted in a family of very effective aircraft-laid sea mines.

The second phase of the operations research was at the tactical level. Typical was the analysis made at the 21st Bomber Command at Guan. At that time the Bomber Command was flying its B-29s in daylight at 20,000 feet, in formation, using visual bombing. The attrition rate against the aircraft was exceedingly high, ranging up to 10 and 15 percent. This was actually in excess of the sustained combat abilities of the aircraft crews.

An analysis was made which showed that in addition to enemy fighter attack, one of the main causes of the heavy losses was the wearing out of engines because of overload resulting from flying to the high altitudes specified and flying in formation. This resulted in many operational ditchings over Japan and on the return trip. The basic heavy losses due to mechanical wear were increased because the weather was good only infrequently and then only for a period of days. During good weather, because of continuously scheduled operations, maintenance crews were overloaded to the point where they were unable to do good work because of excessive fatigue.

After consideration of all the facts bearing on the problem, a preliminary decision was made to consider a course of action in which the aircraft operated in single flights, at night, using radar bombing, at an altitude of about 5,000 feet. An analysis of the Japanese antiaircraft defenses then showed that there was a hole in the defenses at the 5,000-foot altitude and that cloudiness, normally heavy and unfavorable for visual bombing, would prevent the Japanese use of search lights at night. As it was believed that the Japanese had no adequate radar fire control, it was expected that their antiaircraft fire would be ineffective. Also, the Japanese did not appear to have night fighters, and losses due to interception could be expected to be negligible.

It was shown that the use of single flights at night would result in a very much lower rate of engine wear than previously and that very adequate maintenance could be provided if the flights were made on a regular every-other-day basis, which would be possible if radar bombing were used. It was estimated that the cost of such tactics would be a loss of less than one percent as compared to the existing 10 to 15 percent. This prognosis was completely confirmed after the plan was adopted. Finally, it was shown that, because of the ballistics of the mines, mining from low altitudes by radar would be just as accurate as visual mining from very high altitudes.

An improved effectiveness of 20 to 30 times was predicted over-all for the operations at the low altitude. On this basis the tactical plan was approved by General LeMay and was successfully carried out.

The strategic part of this research study considered the over-all shipping situation in Japan. It was shown that shipping within the enclosed Japanese Sea and the enclosed Inland Sea, with access through the Shimonoseki Strait, would be adequate to maintain Japan in the war indefinitely, and that this shipping was essentially invulnerable to submarine and plane attack. Although United States Navy submarines had reduced the Japanese shipping to quite a low level, this level was not as yet low enough to endanger the basic defense of Japan in the beginning of 1945. It was then shown by the analysis that by the use of mines in attacks on the Shimonoseki Strait and the Japanese harbors, the entire shipping of Japan could be sunk and incapacitated by a relatively small aircraft mining effort, a result which might prevent Japan from continuing the war. It was on this basis that General Le May agreed to the use of one bomber group for mining soon after he took command of the 21st Bomber Command. The predicted reduction of the shipping occurred and was quoted by the Japanese as one of the important factors leading to the surrender of Japan.

In comparing the results of the sea mining, it was shown that the logistic and military effort was approximately one-tenth as great for a mine attack as for a similar attack by submarine or direct air.

The next four examples are taken from recently reported industrial operations research studies. The first three are published in full in the February 1953 issue of the Journal of the Operations Research Society of America, Volume 1, Number 2.

"THE RELIABILITY OF AIRBORNE RADAR EQUIPMENT" BY DAVID BOODMAN, OPERATIONS EVALUATION GROUP U.S. NAVY*

This is a study of the failure rates of radar sets. This study is now used in the determination of the operational suitability of existing and future electronic mechanisms in aircraft. It is at the technological level.

Boodman's study was made to provide a guide for development research in the design of more reliable equipment of the type using many electronic and electrical components.

He found that in an equipment having lz+t components of age z, the chance that a component of age z would continue to operate to time t is

$$ {}_tP_z = \frac{l_{z+t}}{l_z} = e^{-n\mu T} $$

where μ is the average chance failure rate. The comparison of this equation with the failure rate of one type of aircraft radio tube is shown in Figure 6. Further comparisons with the equation of the fraction of radar sets surviving a time t

*Journal of the Operations Research Society of America, Vol. 1, No. 2, February 1953 of operation are given in Figures 7, 8, and 9.

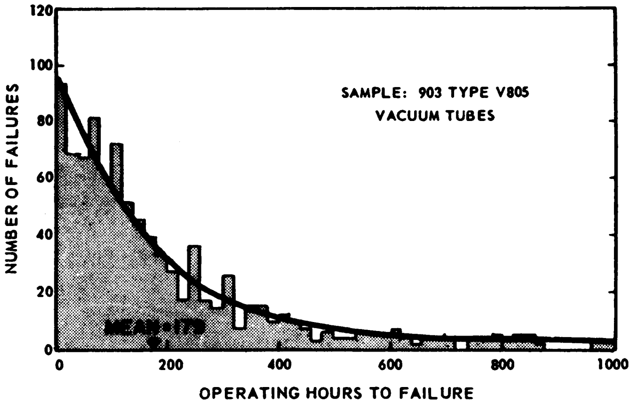

Fig. 6—Distribution of Failure of Aircraft Vacuum Tubes

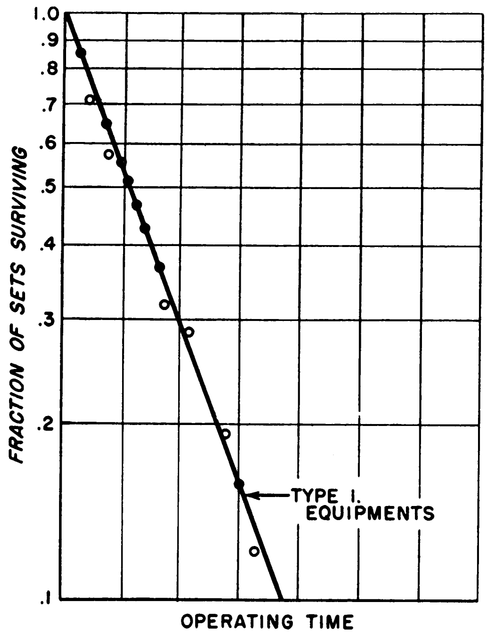

Fig. 7—Failure in Type 1 Airborne Radar Equipment

The value of μ of the sets was taken as $\mu = \mu_V V + \mu_C C$ where μ_V and μ_C V and C, are respectively the failur rates and numbers of vacuum tubes and other components vital to proper operation of the set.

The average failure rates were:

$$\mu_V = 0.0007 \text{ hr}^{-1}$$
$$\mu_C = 0.0002 \text{ hr}^{-1}$$

There was thus found a useful life of 1400 hours for vacuum tubes and 5000 hours for other electrical parts, a small fraction of their bench life.

On this basis an apparatus with 250 tubes and 2500 other parts has a 50 percent chance of surviving two hours. This is exceedingly useful information in developmental research.

A STUDY MADE BY C. W. THORNTHWAITE FOR SEABROOK FARMS, INC. *

Seabrook Farms is a large farming enterprise in southern New Jersey. It is a completely integrated industry which raises vegetables, processes them, quick-freezes them, stores them, and distributes them to housewives all through the eastern half of the United States. This entire operation,

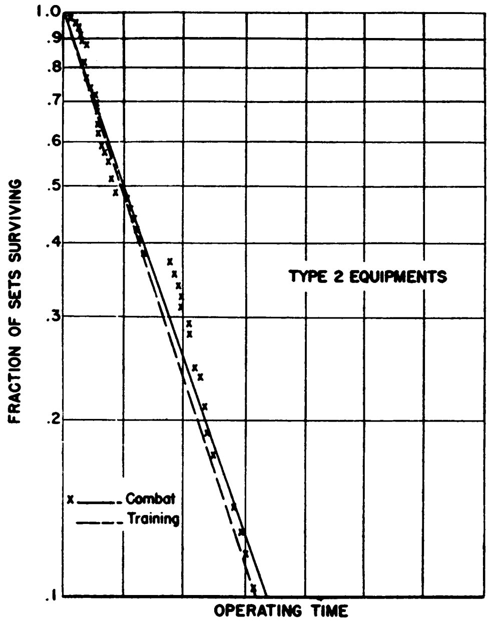

Fig. 8—Failure in Type 2 Airborne Radar Equipment

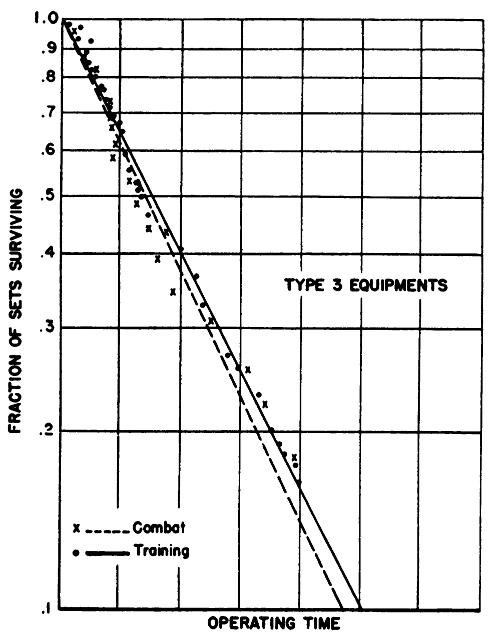

Fig. 9—Failure in Type 3 Airborne Radar Equipment

* "Operations Research in Agriculture," JOURNAL OF THE OPERATIONS RESEARCH SOCIETY OF AMERICA, Vol. 1, No. 2, February 1953.

from farm to table in one production line, provides opportunities for a great deal of operations research. One problem presented to Dr. Thornthwaite was that of predicting when peas would mature. This information was desired so that the peak labor force could be provided to handle the simultaneous ripening of crops in many fields. It was also desired to harvest the peas when they were just ready and of highest quality. At the time that the problem was presented, the division managers of the farm tried to harvest at a rapid rate during the period when peas ripened rapidly. If the work load could not be handled with a 12-hour day, provisions were made for a 24-hour operation, using flood lights to illuminate the fields, and double harvesting crews. This solution was not adequate; not only did queues form in harvesting but equally important queues formed in the pile-up of the product in the factory. The freezing capacity was overtaxed, and eventually the harvest fell behind, so that some peas were overmature and of poor quality when harvested.

The story of the study is a long and interesting one. In his final solution, Dr. Thornthwaite developed a climatic calender based upon the rate of growth of pea plants as a function of calendar time. This climatic calendar was found to apply to most other plants as well. The curve he derived is shown in Figure 10. At Seabrook he found that there are

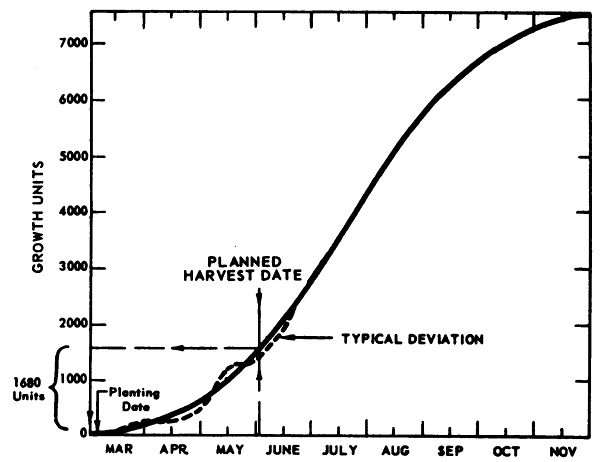

Fig. 10—Crop Growth Curve at Seabrook, N. J.

7, 500 growth units in a year. In comparison Maine was found to have 4, 500 growth units, Pensacola, Florida, 12, 000 growth units. These growth units are a measure of the amount and rate of growth which can take place within any period of time. Second, he found that an accurate growth index could be assigned to each variety of pea (and indeed to any other vegetable). Now, such facts as these require a great amount of experimental data before the values used in scheduling can be firmly established. For preliminary decision, made on the basis of these experimental data and data on all other operations at Seabrook, Thornthwaite proposed to reschedule planting according to the climatic calendar, in such a way that a very even rate of maturing would occur day by day just within the capacity of the harvesting, freezing, and storing facilities. He proposed to eliminate the queues by eliminating randomness in ripening. A stabilized labor force was proposed just adequate to meet the average labor need, peak labor being met by other members of the farm families. By using the climatic growth curve, and the growth indices of the various pea varieties, which had a range of about 25 percent, it was possible to schedule pea planting so that at harvest time peas became ripe at a steady and uniform rate, with only small variations due to minor perturbations caused by variations of the climate from the average values. Contingencies due to poor weather, holidays, etc., were easily provided for.

This same scheduling was put into effect in 1950 for everything that was planted at Seabrook Farm. All planting was done according to the climatic calendar. There are still some problems left in this system, which schedules planting in the same way that railroad trains are scheduled. There are still variations due to abnormally cold or hot weather or to abnormally wet or dry weather. Fortunately these produce only the minor peak loads, since the entire harvest is slowed in the same sequence.

As a result of this new course of action, labor costs for harvesting were greatly reduced. Equipment costs were much reduced by elimination of excess plant capacity, excess canning capacity, and elimination of equipment such as flood lights, and other items for night operations. The entire farming operation, including labor, was stabilized as a result of the vegetable dispatching system. It is of interest to note the simple and inexpensive nature of the solution.

It is worth pointing out that such excellent results could be achieved easily only in an integrated operation of the Seabrook type.

This is only one of a number of very important operations research studies made by Thornthwaite.

"THE EFFECT OF PROMOTIONAL EFFORT ON SALES" AN OPERATIONS RESEARCH STUDY OUTLINED BY JOHN S. McGEE OF ARTHUR D. LITTLE, INC.*

This is a tactical study concerned with the effectiveness of sales promotions in increasing sales. The company that was studied distributes coffee to a large number of retail grocery stores throughout the country. The promotional effort is conducted by salesmen who distribute at the point of sale, promotional material. The cost of the promotion is high. The company had made studies during the last two decades to determine the best balance between sales volume and an economic amount of promotion. None of these studies led to any clear and definite conclusions.

The questions asked of the operations analyst were:

1. How good is the existing procedure for the selection of dealers whose sales should be promoted?

2. How much further effort is warranted in refining the dealer-selection method?

3. How much promotional effort is justified as long as the present method of directing this effort is retained?

Fortunately, in studying and answering these questions there was ready access to the purchase records of many thousands of dealers, and to the previous results of experiments designed to answer the company's problems.

In the model adopted, dealers were ranked from very good to very poor on the basis of the number of cases of coffee ordered per month. Data were available on the effect of sales promotion on fractions of the dealers ranging from the top 30 percent to 100 percent.

It was found that with sales promotion given to all the dealers the fraction of dealers f(n) order n cases per month was given by

$$f(n) = \frac{S^n}{(S+1)^{n+1}} \qquad (1)$$

where S is the average number of cases per dealer averaged

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over all dealers. The fit of the equation to the data is shown in Figure 11.

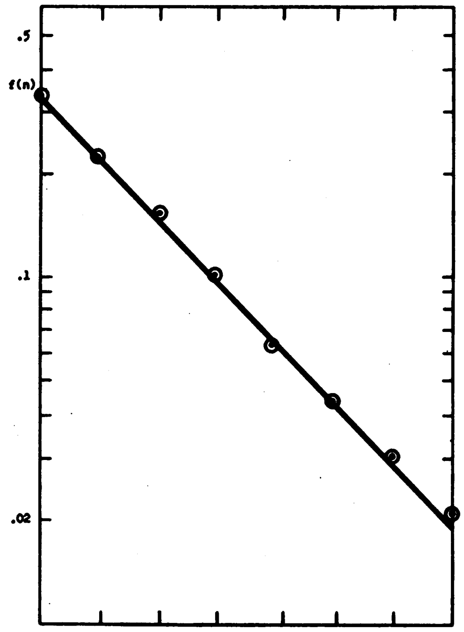

Fig. 11—The observed fractions of dealers ordering n cases in a month: all dealers given special promotional help. The full line is a plot of the equation using S = 2.

It was then shown that when the top fraction of the dealers was given sales promotion, the fraction ordering n cases was

$$f_{np}(n) = \frac{S^n}{(S + g + 1)^{n+1}} \quad (2)$$

where g = (a/1-a) and a is the fraction of top dealers promoted. The fit to the observed values is given in Figure 12.

The relative efficiency due to varying amounts of promotion is shown in Figure 13, and is the percentage increase due to selection of the percentage a as compared to a random sample selected for promotion.

Finally, it was found that profits due to promotion were opitimized when

$$a = 1 - \left(\frac{1}{N_{sv}}\right)\left[\frac{d}{da}\{C(B) + C(a)\} - i\frac{d}{da}\{I(B) + I(a)\}\right]. \quad (3)$$

where N the number of dealers.
v the value per case of coffee
C(B) the cost of producing and distributing a volume B of product.
C(a) the cost of promoting a fraction a of dealers.
i the interest desired from investment.
I(B) capital required to support production B.
I(a) capital required to support promotion a.

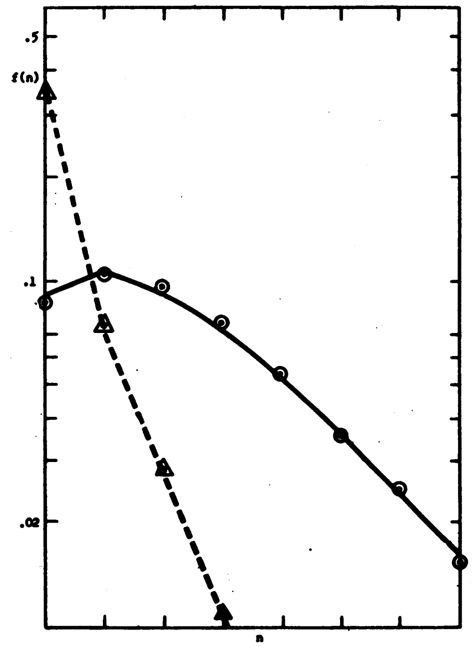

Fig. 12—The observed fractions of dealers ordering n cases in a month. Those normally receiving promotional help are plotted as circles, and those normally not receiving promotional help as triangles. The full and dotted lines are plotted from appropriate equations.

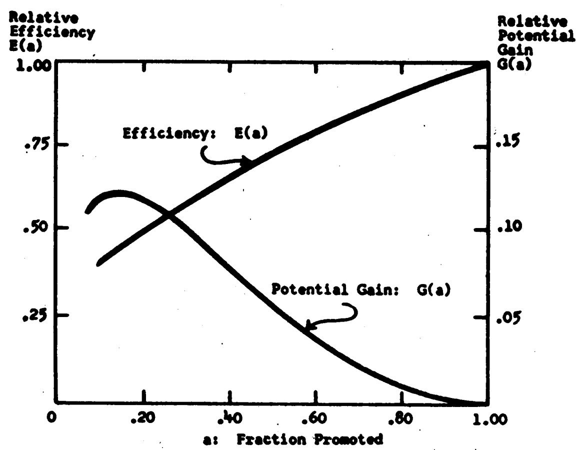

Fig. 13—Relative efficiency of distribution of promotion and potential gain in sales.

This theoretical analysis provided measures very useful in designing company tactics and strategy, not only for sales promotion, but also for general company operations.

STRATEGIC OPSEARCH BY THE PUERTO RICO INDUSTRIAL DEVELOPMENT COMPANY WITH THE AID OF ARTHUR D. LITTLE, INC.

The problem was: "How can Puerto Rico, which has virtually no natural resources and which has a birth rate double that of the mainland United States provide for its people a standard of living comparable to that of the mainland United States?"

The Development Company called Arthur D. Little, Inc., was called in as consultants. The insular government, through its Development Company and with aid from Arthur D. Little, Inc., then examined all phases of the problem--psychological, social, and economic.

Their combined activities resulted in a carefully thought out program for establishment of new industries which would give to Puerto Rico a broader and more stabilized economy. This program helped to introduce such industries technologically; developed and proposed programs for tax problems growing out of introduction of such industries; conducted market analyses and market studies to help sell the island's products.

The results of these studies, which were aimed at a whole system and not at any individual problems, were put into effect and the results speak for themselves.

The Puerto Rican Rum Promotion is an example of one detailed operation in the over-all approach to the island's problems. The initial studies were made by A. D. Little, on behalf of the Development Company. With tax revenues from rum reduced from a wartime peak of some $65,000,000 annually to approximately $4,000,000 in the first postwar year, it was recommended and decided that an advertising and sales promotion program to increase the market for Puerto Rican rum in the United States would be undertaken. This one activity, in which importers in the United States cooperated, resulted in doubling rum shipments to the United States in 1949, the first year of its operation.

The effect of the plan as executed led, in six years, to the following improvements in Puerto Rico's position:

Puerto Rico's world commerce up 250 percent;
Income tax payments by individuals in Puerto Rico up 400 percent;
Property evaluation increased only by 30 percent, indicating a healthy but noninflationary economy;
Puerto Rico's public debt cut in half;
School enrollment up 70 percent;
College enrollment doubled; and
The island electric power production more than doubled.

In comparison with surrounding Latin American countries the indices showed:

	Puerto Rico	Mexico	Argentina
Kilowatt hours per person	200	121	190
Foreign Trade	216	42	110
Literacy	68%	55%	85%

On the whole, these indices are quite favorable to Puerto Rico in view of its much poorer situation with repect to natural resources.

PROBLEMS IN OPERATIONS RESEARCH

I think that I have made it clear that one of the primary problems of the operations analyst is the translation into executive language of conclusions and recommendations resulting from a particular methodology. Having translated his results into good common sense executive language, the analyst has the responsibility of selling his particular conclusions and recommendations to the decision making system, including the executive, and explaining the advantages together with the disadvantages. I have found this to be exceedingly important. I have never found it adequate simply to place a report on one single executive's desk with the implication, "here it is, take it or leave it". An operations research study becomes effective in proportion to the amount of effort spent in communicating the effects of the research to the whole system as well as the executive and clearing up with the executive on a personal basis all of the many questions involving the validity of the study. This is especially important in large organizations where the executive is subject to pressures from many subempires within his organizations. He has particular pressures from his sales and operating organizations, from his production organizations, and even from his research and development organizations, which are usually reluctant to undertake any drastically new course of action desired by management, even though this may be highly profitable in the long run to the over-all organization. Very few analysts are adept at or recognize the need for such multilingual ability on their part. As a result, much good operations research is never used.

I want to point out frankly that operations research has many other severe limitations. It has still to prove itself and achieve recognition. It can do so only on the basis of performance.

I regard the following factors as the most severe limitations in industrial operations research:

1. The lack of basic information on human behavior;
2. The usual lack of adequate information on competitor intentions and capabilities; and
3. The extreme difficulty in getting highly skilled specialists from very diverse and often antagonistic disciplines to work well as a closely integrated team.

In the Operations Research Office it is this last factor which receives our greatest attention, i.e., attempts to form smooth-running teams composed of professionals coming from a variety of physical, social, and engineering sciences, as well as from operations.

Operations research has been vigorously opposed by many economists and econometricians. This is a curious attitude which I do not pretend to understand. On the other hand, many industrial engineers and management consultants have adopted operations research as a technique that they could learn to use as a tool in their own professions.

I, myself, believe that each of the three disciplines, i.e., industrial engineering, operations research, and management consulting, serves particular aspects of the executive's need for help in designing new courses of action I believe the three are mutually supporting. Each will benefit if all are professionally connected through affiliations of their respective societies and the establishment of mutually acceptable standards. I hope this can occur soon.

In summary, it is evident that I have been describing a method of predicting the practical outcome of an industrial operation by constructing a scientific model which accurately describes the operation and permits prediction of future actions.

A definition of Operations Research is then:

"Operations research is the prediction and comparison of the values, effectiveness, and costs of a set of proposed specific courses of action involving man-machine systems and based on a model of the action which has been analytically described by a logical and, when feasible, by a mathematical methodology, and which has had the values of the basic action parameters determined either from an historical analysis of past actions or from designed operations experiments. Most importantly, because all human and machine factors are meant to be included, an estimate of the the uncertainty in the predicted outcome, and in the values, effectiveness, and costs of the proposed actions, is provided."

The methods of operations research are straight forward They can be adopted and used by anyone who employs common sense supported by some technical training. It is hoped that operations research will be widely adopted by industry.

Firms employed by industry to do operations research:
Alderson and Sessions - Philadelphia, Pa.
Armour Research Foundation, Illinois Institute of Technology - Chicago, Ill.
Arthur D. Little, Inc. - Cambridge, Mass.
Booz, Allen & Hamilton - Chicago, Ill.
Davee, Koehnlein & Keeting - Chicago, Ill.
Stanford Research Institute - Palo Alto, Calif.

Firms having their own opsearch groups:
Atlantic Refining Co. - Philadelphia, Pa.
Bell Telephone Laboratories - Whippany, N. J.
Curtis Publishing Co. - Philadelphia, Pa.
E. D. Smith & Co. - Silver Springs, Md.
Giant Food Stores - Washington, D. C.
Melpar, Inc., Westinghouse Air Brake Co. - Alexandria, Va.
Metropolitan Life Insurance Co., Actuarial Division - New York, N. Y.
Seabrook Farms, Inc.- Seabrook Farms, N. J.
Sun Oil Co. - Philadelphia, Pa.
U. S. Rubber Co. - Detroit, Mich.
U. S. Time Corp. - Waterbury, Conn.

Firms doing opsearch for military establishments:
American Institute for Research - Pittsburgh, Pa.
American Power Jet, Co. - Ridgefield, N. J.
Baird Associates - Cambridge, Mass.
Battelle Memorial Institute - Columbus, Ohio
Beers & Heroy - Dallas, Texas
Booz, Allen & Hamilton - Chicago, Ill.
Broadview Research & Development Corp. - Burlingame, California
Cooperative Research Foundation - San Mateo, Calif.
Curtiss-Wright Corp. - Columbus, Ohio
Delta Research & Development Corp. - Rouston. La.
Dunlap & Associates - Stamford, Conn.
Emhart Manufacturing Co. - Hartford, Conn.
Experimental Towing Tank, Stevens Institute of Technology - Hoboken, N. J.
Haller, Raymond & Brown - State College, Pa.
International Public Opinion Research, Inc. - New York N. Y.
Midwest Research Institute - Kansas City, Mo.
Smith & Davis, Inc. - Silver Spring, Md.
Snow & Schule, Inc. - Cambridge, Mass.
Stanford Research Institute - Palo Alto, Calif.
Technical Operations, Inc. - Arlington, Mass.

Military opsearch organizations:
Air Force -- Operations Analysis Division, The Directorate of Operations, Hdq. USAF - Washington D. C.
Air Force -- RAND Corp. - Santa Monica, Calif. & Washington, D. C.
Army -- Operations Research Office - Chevy Chase, Md.
Joint Chiefs of Staff -- Weapons Systems Evaluation Group -- Washington, D. C.
Navy -- Operations Evaluation Group - Washington, D. C.
Army -- Operations Research Group, Chemical Corp., Edgewood, Maryland

British Research Associations doing opsearch:
The British Boot, Show & Allied Trades Research Association - Kettering.
British Electricity Authority - London
British Iron and Steel Research Association Institute - London
National Coal Board - Cheltenham, Gloucester
Road Research Laboratory, Department of Scientific and Industrial Research - Harmondsworth, Middlesex
The Shirley Institute (The British Cotton Industry Research Association) - Didsbury, Manchester.

Seminar Courses offered in opsearch:
Case Institute of Technology
Columbia University
The Johns Hopkins University
Massachusetts Institute of Technology
Pennsylvania State College
University of Illinois

The following list comes from the Operations Research Committee of the National Research Council with the remark that these firms are "strongly interested in establishing an Operations Research program":
The Baltimore and Ohio Railroad Co. -Baltimore, Md.
Chrysler Corporation - Detroit, Michigan
The Chesapeake & Ohio Railway Co. - Cleveland, Ohio
Commercial Solvents Corporation - Terre Haute, Ind.
Eastman Kodak Co. - Rochester, New York
General Electric Co. - Richland, Washington
Minnesota Mining & Manufacturing Co. - St. Paul, Minn.
Pillsbury Mills, Inc. - Minneapolis, Minn.
Republic Steel Corporation - Cleveland, Ohio
The Royal Swedish Academy of Engineering Sciences - New York, N. Y.
Schenley Industries, Inc. - New York, N. Y.
South African Council for Scientific & Industrial Research Pretoria, S. A.
Standard Oil Company, - New York, N. Y.
United Fruit Company - Boston, Mass.

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Los Angeles
WOOD, D. O.
Lockheed Aircraft Service
Burbank
WOODS, H. D.
Bendix Aircraft
Burbank
WRAY, W.
Rohr Aircraft Corp.
Chula Vista
WYLIE, M. R.
Bendix Aviation Corp.
Kansas City, Mo.
WHEELER, Charles E.
Bendix Aviation Corp.
Kansas City, Mo.
WRIGHT, Jack J.
Guchitz Control
Los Angeles
ARNOLD, A.
Hughes Aircraft
Culver City
BUEHLER, H.
Hughes Aircraft
Culver City
CHRISTMAN, C. W.
Hughes Aircraft
Culver City
CRAIG, W.
Hughes Aircraft
Culver City
EVANS, Barton
Hughes Aircraft
Culver City
FORMAN, R.
Hughes Aircraft
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GILLESPIE, H. L.
Hughes Aircraft
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GOODMAN, David
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HOWATT, T.
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HYNES, J. P.
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DENZ, D.
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OLDHAM, Dick
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POOLE, Robert M.
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SAWYER, John W.
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THATCHER, J. F.
Hughes Aircraft
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BODERMAN, Al.
Hughes Aircraft
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BRADLEY, Chuck
Hughes'Aircraft
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ERICKSON, Art
Hughes Aircraft
Culver City

LUIRETTE, Bob
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SIMON, C. E.
Hughes Aircraft
Culver City

ALDEN, J. I.
U.S.N. Ord. Test Station
China Lake
BRAVO, A.
U.S.N. Ord. Test Station
China Lake
CHAPMAN, L.
U.S.N. Ord. Test Station
China Lake
CLEARY, George
U.S.N. Ord. Test Station
China Lake
DEWING, D. L.
U.S.N. Ord. Test Station
China Lake
DOMBROW, R. J.
U.S.N. Ord. Test Station
China Lake
DOUGAN, F. A.
U.S.N. Ord. Test Station
China Lake
FOSTER, P. P.
U.S.N. Ord. Test Station
China Lake
HABER, L.
U.S.N. Ord. Test Station
China Lake
JENNISON, J. H.
U.S.N.Ord. Test Station
China Lake
LAWSON, W. H.
U.S.N. Ord. Test Station
China Lake
LOYE, Mary Alice
U.S.N. Ord. Test Station
China Lake

MARCOVICI, H.
U.S.N. Ord. Test Station
China Lake
McCALLICK, C. A.
U.S.N. Ord. Test Station
China Lake
McGIBBENEY, J.
U.S.N. Ord. Test Station
China Lake
MENGHELLI, Hugo
U.S.N. Ord. Test Station
China Lake
MORGAN, W. C.
U.S.N. Ord. Test Station
China Lake
NIELSON, R.
U.S.N. Ord. Test Station
China Lake
PFEFFERKORN, O. T.
U.S.N. Ord. Test Station
China Lake
RAGSDALE, R. A.
U.S.N. Ord. Test Station
China Lake
REESE, T.
U.S.N. Ord. Test Station
China Lake
REICH, Arthur
U.S.N. Ord. Test Station
China Lake
RICHARDS, F. L.
U.S.N. Ord. Test Station
China Lake
SAPP, W. F.
U.S.N. Ord. Test Station
China Lake
SCHLIESTATT, G. V.
U.S.N. Ord. Test Station
China Lake
SWORD, B.
U.S.N. Ord. Test Station
China Lake
TYLER, A. E.
U.S.N. Ord. Test Station
China Lake
UIELLENAVE, Howard
U.S.N. Ord. Test Station
China Lake

ALLEN, C.R.B.
ARMSTRONG, R.
BARNES, Mrs. R. M.
BARNES, Ralph M.
BOELTER, L. M. K.
BOGENRIEF, Charles A.
BRECKAN, Erling A.
BUCHELE, R. B.
BUFFA, Elwood S.
CARLSON, John G.
CARRABINO, Joseph D.
CARRIGAN, R.
COLEMAN, Edward P.
CRAWFORD, James R.
CROSS, Frank W.
DEMANGATE, D. C.
FIRSTMAN, S.
GALUZEWSKI, R.
GARY, G.
GILBRETH, Lillian M.
GOTTLIEB, M. S.
GRANDI, L. L.
GUSTAT, George H.
HOPKIN, R.
JACOBY, Neil H.
JOHNSON, Ellis A.
LOHMANN, M. R.
LOWRY, Stewart M.
MALCOLM, D. G.
MANILDI, J. F.
MAYNARD, B. I.
McCAULEY, B.
MILES, L. D.
MOONEY, Marilyn
O'NEIL, R. R.
ORTON, DWAYNE
PAYNE, M.
SALVESON, M. E.
SANDLAND, C. N.
SATTLER, R.
SHAPPELL, N. H.
SANNENSHEIN, C. L.
STAUB, D.
THORPE, C. Lloyd
WARREN, E.
WEISER, P.
THUE, H. W.

RESULTS OF INTEREST QUESTIONNAIRE

Distributed at Fifth Annual Industrial Engineering Institute

Berkeley, January 29, 30, 1953

Number in Attendance: 410 Number of Questionnaires returned: 247

1. What size do you consider your company?
   Small 28 Medium 106 Big 97 No Indication 16

2. Attendance at previous Institutes

Attendance at previous Institutes	Number
1st - 1949	42
2nd - 1950	52
3rd - 1951	58
4th - 1952	93

3. Compare general interest of this meeting with others attended.
   Better 73; Same 38; Worse 4

4. How often would you attend institutes on Industrial Engineering?
   Annually 152; Semi-annually 79; Quarter-annually 14

5. Should Institute be held on Friday-Saturday as at present, 147
   or on Thursday-Friday? 88

	Yes	No
6. Did your company allow you time off to attend?	229	9
If on Thursday-Friday?	157	18
7. Did your company pay your registration fee?	177	61
8. In planning future Institutes would you like to have:		
a. More treatment of problems of smaller business?	102	35
b. Simultaneous sessions for smaller & larger business?	130	35

9. Topics preferred for next Institute. (Weighed by preference)

	Pref	Checked only
Human Problems	174	40
Work Simplification	139	24
Production Engineering	129	25
Cost Control Systems	125	21
Organization Problems	119	31
Engineering Economy	115	26
Office Work Simplification	107	22
Time Study	97	9
Production Planning	95	21
Wage Incentives	95	17
Smaller business Problems	94	15
Standard Data Systems	84	12
Training Problems in I. E.	64	16
Quality Control	55	14
Plant Layout	51	18
Detailed I. E. Research	48	10
Safety Engineering	10	2

10. How did you hear of this program?

Direct mail from University	43%
Company	24%
Society	20%
Friend	10%
Newspaper story	3%