The Graduate House, 
Massachusetts Institute 
of Technology, 
Cambridge 39, Massachusetts 
May 16, 1949.

Professor Joseph S. Newell 
Secretary of the Faculty 
Massachusetts Institute of Technology 
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the requirements for graduation, I herewith submit a thesis entitled, "The Economic Selection and Replacement of Manufacturing Equipment".

I wish to express my appreciation to Professor Ronald H. Robnett, Professor Thomas M. Hill, Professor W. Van Alan Clark, and Mr. George L. Smith for their assistance and many helpful suggestions.

Sincerely yours,

Lindsay L. Livengood, Jr.
"Through the use of constantly improved machinery, the path to progress lies."

Dr. Julius Klein, former Assistant Secretary of Commerce of the United States.
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INTRODUCTION.

The Problem:

The economic selection and replacement of manufacturing equipment is one of the most important problems that confront modern management. Manufacturing equipment is constantly being improved and developed, and, unless manufacturers avail themselves of the economies of modern cost-reducing equipment, their competitive situation in their industry is likely to be disastrously impaired. A business can remain competitive only as long as its plant and equipment is kept up-to-date either through extensive continuous rehabilitation or through the purchase of new modern equipment.

Millions of dollars in capital are being invested in manufacturing equipment every year, and by many companies without either a definite purpose or according to a well-conceived plan. It indeed seems odd that so little attention is currently being paid to definite long-time planning of equipment policies. Most companies seem to have no definite equipment replacement policy at all, and many of those that do have a policy seem merely to employ some rule-of-thumb method that, in my opinion, is not suitably adapted to present needs. Within the last few years, large additions have been added to plant capacity, but comparatively little advancement has been made in equipment modernization programs.

Industrial executives often complain that they have no money to spend for the modernization of their machinery and equipment. What these executives do not realize is the fact that they may be paying
for machinery and equipment modernization over and over again through breakdowns and repairs which result in both a loss of production and high costs. A company may actually be paying for equipment once every two or three years, but still have nothing whatever to show for it until it actually purchases and installs new equipment.

It is absolutely essential that industrial executives be in a position to recognize and to determine the economic characteristics of existing equipment in their plant and also of that which they are contemplating purchasing, so that they can know definitely when a piece of equipment should be replaced. Only through adequate cost accounting records and by an intelligent replacement study can this be done. Some sound basis must be provided to assure the original selection of the most appropriate type of equipment for the performance of the given task or service, and later its replacement by new and up-to-date equipment of sufficient additional economy of operation to justify the disposal of the old equipment and the investment of additional capital in the new.

A great many articles on this subject of equipment selection and replacement have been published during the last two decades. Numerous attempts have been made to devise methods and formulas, the use of which would assure proper replacement analyses from the economic standpoint. However, only a very few, if any, of these methods and formulas which have been published, or that are being used in industry today, have proven to be entirely satisfactory. Most of them either do not consider all the fundamental factors involved in a replacement analysis, or they are too complicated or too difficult really to be applied by plant engineers and operating executives on whom the problem of re-
placement falls. In this connection, what these engineers and operating executives need most of all is an understanding of the major principles that underlie this problem of equipment replacements and, also, a practical method with which a replacement analysis could be properly performed. It is therefore timely to bring out an up-to-date treatise on this subject of equipment selection and replacement.

**Purpose:**

This thesis has two general purposes, which may be stated as follows:

(1) To present in a single volume all the major phases and underlying principles of equipment replacement, and thus to guide in their thinking on this subject the many engineers and operating executives who concern themselves with the problems of replacement. I have attempted to set forth an analysis which I feel fits the facts accurately and which I hope will be of some usefulness as a basis upon which to ground replacement decisions.

(2) To suggest, discuss, and illustrate a practical method which may be used in making replacement analyses, thus providing these engineers and operating executives a means of checking for themselves the savings that might result from investments in modern up-to-date manufacturing equipment.

**Method:**

This thesis is the result of my own thinking and analyses of the many problems that confront modern management in the selection and replacement of manufacturing equipment. By means of personal conferences
with industrial executives of plants located in the Boston area, I have attempted to become aware of the current ideas on the subject and to gain firsthand information concerning present techniques of making replacement analyses. In addition, I have availed myself freely of the works of other writers who have published articles on this subject during the last two decades, and have endeavored to give full credit for this assistance where such help has been used. Such information as I have obtained is the basis around which I have built this thesis.

Scope:

An endeavor has been made to discuss all the major phases and principles that underlie adequate and intelligent replacement policies. A section has been included in which a cursory discussion of the practical aspects of cost determination is presented. Another section is devoted to a discussion of the several methods that are currently being used in industry to make replacement analyses and of some of the common fallacies in present methods of which industrial executives may not be aware. Finally, a proposed method of making replacement analyses is suggested, discussed, and illustrated. Throughout this thesis I have endeavored to select and incorporate illustrative matter that would be adapted to and readily understood by engineers and operating executives.

Limitations:

This thesis is not intended as a manual of detailed facts about the economic selection and replacement of equipment. Instead, it deals with the primary and fundamental principles of equipment selection and
replacement which underlie successful business management and successful investment. Although consideration is given to many factors that bring about the desirability of equipment replacements, the emphasis of this discussion of the replacement problem is placed on cost.

The subject matter of this thesis is necessarily much condensed. This subject of equipment replacement is undoubtedly a large one and perhaps too large to permit operating executives and engineers, generally, to acquire an exhaustive knowledge of all its details. In fact, any thesis that would do full justice to this great subject would be many times too large for the purpose for which this work is intended.

Acknowledgements:

For their advice and suggestions and for their very liberal aid and criticism in the preparation of this thesis, I wish to express appreciation especially to Professor Ronald H. Robnett, Professor Thomas M. Hill, Professor W. Van Alan Clark, and Mr. George L. Smith, all of Massachusetts Institute of Technology.

To my former professor at Virginia Polytechnic Institute - Professor Paul T. Norton, Jr. - I owe the great debt of inspiration that prompted me to write a thesis on this subject.

To the many investigators and writers whose publications and ideas are cited throughout this thesis, and to the many cooperative plant executives in the Boston area with whom I have discussed this subject, I wish to acknowledge my deep indebtedness. Acknowledgement of indebtedness to each who, directly or indirectly, has contributed information is impracticable.
SUMMARY.

Several factors tend to motivate equipment replacements. Probably the underlying factor is that of a prospect of keener competition. Then too, there are others, such as the increase in operation or maintenance costs, the development of improved alternative equipment, the increase in service requirements, and improvements being made by materials and parts suppliers.

The results and advantages of adequate replacement policies are many, several of which may be noted as follows: (1) lower costs of production, (2) increase in production, (3) quicker and better service to customers, (4) increase in the general efficiency of human effort, (5) stimulation of business, and (6) the leveling out of the peaks and valleys in the business curve.

There are two major factors that bring about equipment replacements, namely, physical decrepitude and obsolescence. Most replacements, however, are the result of obsolescence. It then becomes necessary that some provision always be made in depreciation allowances to account for it. Never should replacements be linked with the age of equipment, as time is not a factor that determines obsolescence. Obsolescence may be the result of any one of several influences, namely, technological improvements and developments in equipment, changes in product design, changes in manufacturing processes, changes in output requirements, and changes in quality or accuracy demanded. Equipment should be deemed obsolete if money could be saved by replacing it.

One of the main prerequisites of any equipment policy is the availability of adequate resources with which to finance replacements. Some companies set up a replacement fund, which consists of appropriations
of profits. But, because such a fund must be invested in the so-called safe securities, on which interest rates are low, other companies prefer to finance replacements through the company surplus, through loans from commercial banks and credit houses, or through a financing plan offered by the equipment suppliers.

All equipment policies must have as their basis sound and adequate cost accounting systems. Only through accounting records can costs of equipment operation be known and compared. Correct costs will also go a long way in distinguishing obsolete equipment. When the facts are all available, replacement decisions are relatively easy to make.

The economic superiority of one item of equipment over another can be properly determined only on the basis of equal expected services. All costs and revenues which are unaffected by the choice of equipment may be omitted from the replacement analysis. But, consideration must be given to certain fundamental cost factors. One classification would include the costs of ownership - depreciation, interest on investment, taxes, and insurance - which are computed on the basis of the investment in equipment. The investment in proposed equipment, which serves as the basis of costs of ownership, should be the total cost of the equipment in-place and ready to operate. For the existing equipment, the basis should be the net realizable value of the equipment at the time. Unamortized value of existing equipment should not affect the replacement decision. In the replacement analysis the depreciation charge is based on the period of time in which the equipment is expected to pay for itself, and the interest charge is that rate of return which would make the investment attractive, consideration being given to the risks involved.
Another classification of cost factors would be operating costs - direct labor, indirect labor, materials, repairs and maintenance, power, floor space, supplies and lubricants. Each of these costs must be computed or estimated, and charged against the equipment. Because of a probable error in basic data used, it will generally not pay for management to be finically scrupulous in their calculations nor in their search for minor and uncertain differences in economic performances between alternative equipment.

There are several methods by which a replacement analysis may be made. The most commonly used methods compute either the rate of return on additional investment or the number of years required for the new equipment to pay for itself. Some companies actually establish a fixed time period in which equipment must pay for itself to justify installation, while others take the stand that each purchase must be made strictly upon the merits of the case.

Because of several fallacies in present methods and of the shortcomings in the use of formulas, a more practical method of making replacement analyses would be to prepare an orderly tabulation of annual fixed and operating charges for each alternative piece of equipment. If this is done, the difference between total annual charges would be an indication of the relative advantage of one item of equipment over another.

Regardless of the particular method that is used, no final decision should ever be made on the basis of cost comparisons alone. Consideration must also be given to intangible and judgement factors which have no immediate money value, but which may nevertheless provide the ultimate weight of evidence in favor of or against a given piece of equipment. Replacement problems are generally of such a complexity and importance as to justify the attention of experienced executives. They should not be be handled by clerks.
I. UNDERLYING CONSIDERATIONS IN EQUIPMENT POLICIES.

A. Motivating Forces of Equipment Replacements.

In view of the keener competition to come and a narrowing of margins throughout the business structure of this country, it is absolutely necessary that plant executives begin to realize the importance of bringing their equipment up to date. Unless a well-conceived replacement program, based on facts, is undertaken, many manufacturers are very likely to find their competitive position in their industry greatly weakened, and just at a time when competition will be the fiercest and most acute. Plant executives can not afford to hesitate in discarding equipment when modern and improved types can prove an advantage. Those that refuse to discard obsolete equipment simply because it apparently is still in good physical condition and capable of providing about the same service as when installed may eventually find themselves out of business. A great many companies are beginning to realize this fact, that unless they plow back their earnings into better equipment and thereby ready themselves for a market that will demand lower prices and better quality, they may be compelled to sit back and watch their competitors take away their market through the aid afforded by modern cost-reducing equipment. Therefore, it would seem safe to say that the underlying motivating force that brings about equipment replacements is the prospect of keener competition.

And there are other motivating forces which may be noted, as follows:

(1) An increase in operation or maintenance costs, which result when the cost of labor is increased, when repairs become too frequent, or when costs increase generally as the result of the equip-
ment's physical deterioration.

One of the principal factors that is forcing employers to the use of more and better machinery is the present high cost of labor. If labor costs continue to rise, more and more plant managers will be impelled to seek that equipment which will either eliminate labor or reduce the skill required of operators on the machine.

In some cases, this increase in operation and maintenance cost may be merely a result of the equipment's physical wearing out. If this is the sole motivating force of equipment replacement, no particular replacement problem would arise. Equipment identical to that which has worn out need only to be considered and installed.

(2) The development of improved alternative equipment, such as through an improvement in design, which will result in operating economies. In other words, the existing equipment has become obsolete. If obsolescence brings about replacement, plant executives are forced to seek the more profitable investment, which may, in many cases, necessitate the purchase of an entirely new type of equipment.

(3) An increase in service requirements, which may be the result of either a change in demand for the product, which makes the existing equipment inadequate to produce the desired production, or a change in the accuracy or the quality demanded of products.

Inspection of purchased products by both industrial users and by the consumer is becoming more critical and severe, and the degree of accuracy that was acceptable during the war years of 1941 to 1945 will not suffice in the future. Under such circumstances, it becomes absolutely necessary to replace existing equipment with new equipment which will provide the desired service.
(4) The prospect of an increase in price for new equipment or a present high realizable value for the existing equipment in the plant. Either of these two factors will tend to accelerate replacements.

(5) Improvements made by materials and parts suppliers. As an example, one plant manager had to replace equipment in order to be able to handle a lighter weight glass bottle developed by his glass bottle supplier.

B. Expansion:

The need for expansion of productive facilities is often a reason for the purchase of new equipment. Although, in such cases, a plant manager is not concerned with all the problems involved when considering replacement of one piece of equipment by another, many of the same problems still exist. It is believed, therefore, that a cursory discussion of plant expansion has a proper place in a thesis devoted mainly to the replacement of equipment.

In expansion, even though there is not present the necessity of an everlasting alertness to recognize equipment obsolescence and for a comparative-cost replacement analysis, a study must still be made to assure the selection of the most appropriate piece of equipment for the performance of the given task or service. The proper selection of equipment is common to both expansions of productive facilities and to equipment replacements.

If the need for expansion arises as a result of increased business, a study should be made to determine whether this increase is temporary or whether it is permanent. No expansion should be made
until it has been concluded, as definitely as possible, that this increase in business will continue for a considerable length of time. If this prerequisite is satisfied, attention must next be directed to the selection of equipment to provide the service desired. The process engineer should be able to provide the information pertaining to the specifications of the job and the mechanical and operating specifications of each piece of equipment. These specifications must be known to assure that the correct type of equipment will be used for each job. But it is the responsibility of the plant executive to know the equipment's economic characteristics.

A following section of this thesis is devoted to an annual cost method of comparing alternatives, which would be particularly adaptable to the determination of the economic characteristics of several proposed pieces of equipment.

C. Objectives of Replacement Policy.

From an economic standpoint, the overall and ultimate objective of an equipment replacement policy is to make certain that capital is always invested in that equipment which will earn the greatest profit. Whenever plant equipment becomes worn out or obsolete, costs of operation and maintenance naturally will be in excess of that which could be realized on modern up-to-date equipment available to take its place. Only through the replacement of such existing equipment with the new can costs be reduced and greater profits be realized. One author has gone so far as to say that "there is only one reason
for buying a machine tool, and that is to make money" (1). This state-
ment obviously is correct, for whether we invest our capital in build-
ings, in equipment, or in labor employed, our purpose and objective
is to produce a profit on the invested capital.

However, there are several specific objectives that industrial
executives may have when considering equipment replacements, which
may be noted, as follows:

(1) To reduce costs of operations and maintenance. The re-
placement of a piece of equipment is most commonly considered because
the new equipment will effect an economy in direct labor, in materials,
in maintenance, in power, in floor space, or in some other way, and
it is from this cost standpoint that this thesis is primarily written.

(2) To improve the accuracy or quality of the product. Improve-
ment in quality can generally be expected to increase sales volume,
and it is through this increase in sales volume that the true profits
from this type of replacement comes.

(3) To increase production. If additional equipment is needed
to meet the increased production schedules, obviously, the best machine
or combination of machines must be selected and installed to provide
the desired service. Then too, increased production per unit of
time is often a primary objective of equipment replacements in many
companies. But even these companies find it difficult to realize

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(1) Berna, T., Machinery Replacement and Depreciation Policy.
    Journal of Engineering Education, 38, p. 542-7, April (1948)
that equipment which was installed only a few years before has become obsolete and could be profitably replaced. "It has been stated that the machine tools displayed in the Machine Tool Show of 1947 will produce, on the average, 33 1/3 per cent more than earlier designs, even though the earlier designs are those developed in the thirties and built throughout the war" (1).

These three objectives explain the fundamental reasons why industrial executives will discard old equipment and replace it with new. In addition, plant executives have also expressed the following as objectives at one time or another of their replacement policy:

1) To better working conditions.

2) To provide a better service to customers.

3) To accommodate style changes and changes in the design of product.

4) To eliminate delays and costs incident to subcontracting work.

5) To smooth out the production rate curve.

6) To eliminate disagreeable or particularly arduous labor.

7) To eliminate the necessity for highly skilled operators.

8) To do away with human labor, thereby eliminating the many idiosyncrasies of the human element - sickness, tardiness, quirks, etc.

Such a list of objectives is by no means to be thought all inclusive. There are many more, depending on the situation present in

a company at the particular time. Also, it is quite natural for a company to have several objectives in mind when considering the replacement of existing equipment. For example, a cigar manufacturer has expressed the following as its objectives when it was considering the replacement of existing cigar wrapping machines.

1) To get more total production.
2) To get more production per machine.
3) To realize complete modernization in keeping with the new building into which they had recently moved.
4) To provide safer operating conditions (the new machines were provided with an electric eye which would automatically stop the machine when operators stuck their hands in certain dangerous parts of the machines).
5) To better employee morale and decrease labor turnover.
6) To decrease hand labor (the new machines were more automatic).
7) To save material (the new machines had smaller dies to cut the tobacco wrapper).

In a sense, the term "objectives" as used in this discussion, could also refer to "the reasons" why replacements are made.

D. Controlling Factors.

Equipment must be replaced either because it wears out, because it is superceded by equipment that will produce the same service at a much lower cost, or because it is incapable of providing a desired service. Consequently, it would seem safe to say that there are two
major controlling factors that bring about the necessity of equipment replacement, (1) physical decrepitude, and (2) obsolescence.

Obviously, when a piece of equipment wears out as a result of use, or the wear and tear of the elements, both the costs of operation and of maintenance may be expected to increase. The use of equipment, however well cared for and properly repaired, will result in its eventual wearing out, no amount of care and repairing being able to entirely eliminate the physical change that will take place. In addition, there is the action of the elements that will bring about physical decrepitude, whether the equipment is used or not. In fact, it is sometimes the case where the equipment approaches this state of physical decrepitude more rapidly from idleness than from use, because idleness is very often, and naturally, accompanied by a lack of proper maintenance and care.

The old method of equipment replacement was to wait until the equipment wore out, the need of replacement not becoming apparent until plant executives realized that breakdowns and the high costs of operation and maintenance were causing a loss of money. In other words, physical decrepitude was the cause of most equipment replacements.

But today this is generally not the case. There is also that all important factor of obsolescence that must be considered. This factor of obsolescence, unfortunately, does not lend itself to a scientific analysis. We cannot determine definitely when a piece of equipment will become obsolete. About all we can do is to guess as to the length of time before some restless equipment supplier
will devise a new and improved process or piece of equipment that will make it unprofitable for us to keep the existing equipment in operation any longer. In nearly every case the time when obsolescence will occur and its effects are uncertain; it is decidedly a judgment factor.

We can not escape the effects of obsolescence, it is with us always. The business structure of this country is never static, it has been, and will be, dynamic. It therefore becomes the responsibility of industrial executives to make adequate provisions to safeguard the integrity of their capital investment in equipment from the hazards of impending obsolescence.

Too frequently, however, this factor of obsolescence appears at no place in our accounting ledgers, or it is consolidated and thereby obscured by charging, against factory burden, depreciation at a set rate of 10 per cent per year. Because of the difficulties involved in forecasting future technical changes or estimating the time when it would be profitable to substitute new equipment for the old, it is not proposed, however, that separate allowances for obsolescence be set up in our accounting records. Nevertheless, it is absolutely necessary that recognition be given to the probability that the effects of obsolescence will make replacements desirable before the equipment has actually worn out. Some provision must be made in depreciation allowances to account for it. If an arbitrary accounting life is set for equipment, there is always that risk that impending obsolescence will occur before that life has expired.

Probably nothing else has obscured the whole replacement issue more than the persistent linking of replacements with the age of
equipment. Age of equipment is by no means a true measure of obsolescence, which concerns only the economic value of the equipment and not its physical condition. In other words, "equipment replacement is a matter of relative productive costs and not relative machine ages" (1). Equipment two or three years old may be absolutely worthless because of the effects of obsolescence before normal depreciation. As a matter of fact, it is perfectly possible for equipment to become obsolete within a short time after it leaves the maker's assembly department; even while the equipment is being built, other equipment may be on the drafting board that will make the present new equipment obsolete in a year or two. Time is not a factor that determines obsolescence (its effects may be sudden), except so far as permitting the development of new and improved equipment or of changes in demand, in quality, or in design of products. Industrial executives should not assume that all quite new equipment is economical to install or to operate, nor should equipment be condemned as being uneconomical merely because it has been used for a certain number of years. Detecting and replacing equipment that has become obsolete is one of the most important jobs confronting plant executives, and no assistance is obtained from a mere study of relative equipment ages.

But how are plant executives to know when their equipment has become obsolete? Equipment becomes obsolete when its earning power is so much less than that of a new and improved piece of equipment capable of providing the same service that the difference will more

than repay the investment in the new equipment. In other words, as expressed by some authors, (1) "any manufacturing equipment is obsolete if money can be saved by replacing it".

"As the visible evidence and a reminder of the challenge to obsolescence" (2), one company painted service stripes on each machine which were advanced each year. Then, every year the factory superintendent made out a report on every machine that was ten years old or over, showing just how cheaply the work done on the present machine could be done on modern equipment. This procedure enabled the management to decide which machinery it was advisable to replace. There was nothing, however, in the plan that prevented the considering of replacement of a machine before its tenth birthday.

But obsolescence does not necessarily decide replacements. Obsolete equipment that apparently is providing the desired service satisfactorily belongs to that classification of equipment that plant executives are not likely to replace unless savings from the replacement, or losses resulting from continued usage of the existing equipment, can be proved definitely in terms of dollars. The replacement of equipment can be justified only by a determination of the net savings in actual dollars and cents resulting from such proposed replacements; it is a question of actual money to be saved through the replacement.

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A following section of this thesis will be devoted to replacement policies and to a method whereby costs can be compared between alternative pieces of equipment. Through costs comparisons that determine the dollar savings that would result from replacements, the replacement may be justified.

In addition to technological improvements and developments in equipment that make the existing equipment too costly to continue in operation, there are other influences that may bring about equipment obsolescence, which are listed as follows:

1. Changes in the design of the product.
2. Changes in the method of manufacture, or of construction, of the product, which may result from improvements in methods and processes or from the elimination of uneconomical manufacturing operations.
3. Changes in output requirements, which make existing equipment inadequate.
4. Changes in the quality or the accuracy demanded.
5. The demand for the use of existing equipment for certain operations beyond its capacity.

The effects of obsolescence and the rapidity with which it comes will vary between different types of equipment. Obsolescence as a result of improvements in design is less marked for that class of equipment which is more or less universal in its characteristics and of the general utility type. But in those plants employing highly specialized equipment, especially in those cases where mass production makes possible the scientific study of the lowest cost possible in any particular operation, obsolescence is likely to come faster. In the selection
Probably the underlying reason for this lack of funds with which to make replacements lies in our present accounting methods. Most companies accrue depreciation charges annually, usually at a rate of about 10 per cent on equipment, which are set up as a reserve offsetting the original capital investment in the equipment. Because of the accountant's failure to understand and to appreciate the fluctuating requirements for liquid funds, which invariably are the result of a sound replacement policy, no replacement fund is provided to offset the reserves. Then too, the difference between a reserve and a replacement fund is not always appreciated by engineers or those operating executives on whom the replacement problems descend. The precise nature of the reserve for depreciation is often misunderstood, and those persons concerned with replacements must realize that a depreciation reserve never makes available the funds needed to replace equipment.

"At best, the depreciation reserve is a valuation reserve and is not a pile of cash in the back room" (1). It is stated either on the liabilities side of the balance sheet, or as a deduction on the assets side; therefore, it cannot and does not refer to any fund. The depreciation reserve is set up to account for the loss of value of the equipment; it is a deduction through depreciation charges from the book value of plant equipment. The reserve is purely a charge against profits or, in other words, the result of withholding from gross income an amount equal to the estimated loss in value of

(1) Hoagland, H.E., Corporation Finance.
equipment, usually referring to an arbitrary value set for the convenience of the accountant. The annual depreciation charge, which makes up the depreciation reserve, has only one purpose, namely, to recover the capital invested in equipment; it is not made for the purpose of paying for new equipment and does not build up a cash reserve. In fact, the actual cash disbursement for depreciation was probably made at the time the equipment was originally purchased.

The accountant cares not about the actual value of equipment from year to year; his main concern is to follow accepted accounting conventions in writing off capital investments by the time the equipment must be discarded. This procedure, however, will result in assets being retained in the company rather than being regarded as net profits available for distribution to stockholders.

Many authors and industrial executives advocate, however, the actual setting up of a replacement fund which consists of appropriations of profits, distinct from other funds, labeled and available for equipment replacements. In effect, therefore, a replacement fund constitutes an earmarked portion of the profit and loss account. If such a regular funded reserve is set aside each year, the fund need not be completely liquid but can be in the form of money invested in bonds or in other securities held for modernizing equipment. It obviously is desirable that such securities have maturity dates somewhat shorter than the estimated economical life of the equipment in question or that they possess sufficient marketability to provide liquid funds at any time needed.

In theory, a definite replacement fund out of which cash can be immediately obtained for the purchase of new equipment is cert-
ainly desirable. Of considerable importance is the necessity of maintaining the integrity of the original investment in equipment, which would be accomplished by setting aside periodically cash or securities in a fund for replacements in order that the total of those funds set aside, derived from depreciation, plus the value of the equipment as carried on the books will equal at any time the original investment in that equipment. Also, a replacement fund would make it possible to dispose of obsolete equipment and to replace it with the up-to-date without the necessity of disturbing the corporate surplus, of requiring additional capital, or, of refinancing. No financial burden at all would fall upon the company at the time of replacements if depreciation had been fully charged and a fund accumulated that had been properly earmarked for replacement purposes.

Anc, it is absolutely necessary that such funds be properly earmarked and used for no other purpose than for replacements. The fund "should be considered as sacred as a trust fund, and exactly comparable with a mortgage amortization fund deposited annually with a corporate trustee" (1). In fact, some authors have suggested that such a replacement fund be trusteeed to prevent the possibility of directors using it for purposes other than replacement financing or mistaking it for divisible surplus. In other words, the fund must be used only for the replacement of equipment, not for anything else. The company that follows this policy of establishing a replacement fund

will be in a highly fortunate position, especially when replacements are thought desirable at a time when money is hard to get (when the money market is tight).

Similar in many respects to the establishment of a regular funded reserve is the policy of setting up a definite sinking fund to be used only for the replacement of equipment. By paying in a certain amount each year (an annual premium) carrying compound interest, the desired sum would be available at the time decided upon for the replacement of the equipment. Such a policy of establishing a sinking fund may provide funds for the retirement of certain equipment at regular intervals, which in many instances would prove to be a highly effective replacement program. The amount of the annual premium can be determined by reference to any sinking fund table.

Undoubtedly, a replacement fund set aside to be used only for the replacement of equipment has many advantages, but, on the other hand, there are some serious objections to this method of providing funds. In actual practice it is often quite difficult to convince industrial executives that idle cash or securities set aside in such a fund are anything but a waste of valuable capital; and, in a sense, their reasoning is entirely correct. Safety and liquidity are paramount in the use of a replacement fund; hence, funds would obviously be invested in the so-called safe securities on which interest rates are low, generally less than the interest rates at which the company might be borrowing money. For this reason, company management often, and properly, prefer to put the funds back into their own businesses where the return would probably be higher than that on these conservative securities.
In most cases, it would probably be desirable to take replacement expenditures directly from the surplus of the company, this surplus being controlled so that the necessary funds will be available when replacements are desired. In effect, therefore, the equivalent of a replacement fund would be maintained, although it would not be controlled separately or known as such. Many companies have found that the actual setting aside of cash or securities for equipment replacements is not necessary, and they rely on a careful budgeting of their equipment expenditures and a control over their surplus so that funds will be available when needed.

In addition to the use of the company surplus, there are three other means of financing equipment replacements that are used by individual companies.

(1) Some companies borrow funds for replacements from commercial banks when the replacement analysis shows a return of the investment in a fairly short period of time, or when the loan is intended to be refunded by the sale of stocks or bonds when business conditions improve and the money market becomes more favorable.

For a number of years commercial banks did not look with favor upon loans to industrial companies for the purpose of financing fixed assets. However, "for more than two decades, commercial banks have been suffering from decreases in the demand for commercial loans" (1). This increasing difficulty of keeping their resources profitably employed accounts, in part, for a changing attitude on the part of bankers, particularly when the replacement shows a return of the in-

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vestment in a fairly short period of time. However, because of current banking practices and regulations, the financing of equipment replacements can still hardly be expected through bank loans where the replacements will require five or six years to pay for themselves.

(2) Other companies borrow funds from the commercial credit companies, generally on a long-term-installment payment basis, if the prospective savings from the replacement justify this increased cost of financing. "It is quite probable that the facilities of the so-called commercial credit companies will be used more extensively, providing financing charges are reasonable" (1).

(3) Also, many equipment manufacturing companies may offer a financing plan for equipment replacement by selling on a limited time basis, such as 25 per cent cash down payment and the balance payable over a period of six months or a year. Such a plan of financing would meet the financial problem of replacements if equipment replacements were limited to those cases where the investment would be returned in a one year period. The net capital and net profits of most equipment manufacturers do not, as a rule, justify the widespread extension of terms of payment beyond a one year period.

F. Results and Advantages of a Good Replacement Policy.

Companies which have been backward in their equipment modernization programs should undoubtedly take stock of the condition of

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(1) Runge, R.F., Replacement by Formula.
American Machinist, p. 762, Nov. 19 (1931).
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their equipment and inaugurate a regular "housecleaning" throughout their whole plant. Those manufacturing concerns which produce the best quality of goods at the lowest prices can be expected to get most of the market. But both high quality and low prices are the result of having efficient equipment in the plant. Therefore, it seems very probable that there are many companies which would benefit greatly if a more systematic and adequate replacement policy were in use in the company. The results, and the advantages, of adequate replacement policies are many, and of considerable importance, some of which are discussed as follows:

(1) Lower costs of production. Replacement policies have revolutionized manufacturing methods and have brought equipment to a high state of efficiency. Every manufacturer wants lower costs of production, and there is available no more fertile ground for him to search for them than through his equipment. Many companies have found that both operating costs and the costs of maintenance have been reduced through equipment replacements. Lower costs of production may be the result of any of several possible savings that might accrue from equipment replacements.

(a) Savings in direct labor cost through a reduction in the number of machine operators required or the reduction in the skill required on the part of the workmen, which makes possible lower wage rates. In addition, such a reduction in skill required makes it possible for the company to expand production more rapidly when necessary, and without a long, tedious, and expensive period of training new workmen.
(b) Savings in material cost through a reduction in scrap and spoiled work, often even when tolerances are tightened.

(c) Savings in power cost. One company when it replaced a part of its equipment substituted individual motor drives for the former group drives. As a result of having a large number of small motors, each running at a lower average percentage of normal rating and with more frequent starting and stopping, their power factor dropped (1).

(d) Savings in floor space through equipment of a smaller size but of the same or an increased productive capacity. Very often operations which now require several machines may be put on one new machine, which, in a crowded plant, may be a saving in space of substantial value. In addition, replacements often make possible the careful rearrangement and relocation of old equipment, tool cribs, and aisles space, making possible expansion, if desired, without additional buildings. A good replacement policy will bring to the attention of plant management errors in plant layout, in routing, and in manufacturing methods throughout the plant.

(e) Other savings in overhead costs, such as a reduction in supervision accompanying a relocation of departments, a reduction in materials handling costs, or a reduction in inventories made possible by standardization.

(2) Increase in production. This results from the installation of equipment of greater productive capacity or due to the effect of new and modern equipment upon the morale of the operator.

(3) Quicker and better service to customers. A good replacement policy makes possible prompt delivery to customers at the time promised, thereby enabling the company to build up its business reputation. It results in a more accurate, up-to-date, and a better finished product at a lower cost. The quality of the product may be enhanced through the use of more lasting materials, the increased cost of better materials being absorbed through the medium of better machines and better methods.

(4) Effect on employees. It is only human nature to want to work with the latest up-to-date equipment. Those companies with such equipment can attract the best workmen (good mechanics and operators like to work with good machine tools), can demand the best, and can get it from satisfied employees. All men like to operate new equipment, will take more pride and care in keeping it in good shape, and will produce a more uniform quality of work. Increased satisfaction of workmen will be derived from a reduction of fatiguing or heavy physical labor. Even through savings due to a lessening of worker's fatigue, or from a reduction in accidents, cannot be directly measured, they will be included among the final operating savings, the result of an increase in the general efficiency of human effort. Also, there is that psychological effect on workmen, derived from faster production equipment, that induces an ambition or incentive to maintain the rate, or even accelerate it.

But what effect have equipment replacements had on the wages of employees? Labor cost as a whole has been reduced, but the wages of individual employees have been materially increased. In many cases the introduction of new machinery has brought about incentive systems
of wage payment that have materially increased wages and also production. A good replacement policy in all companies would undoubtedly stimulate business and thus reduce unemployment.

(5) Effect on business cycle. Most manufacturers follow a policy of purchasing new equipment only during those periods of great demand for their products. If, on the other hand, a certain amount of equipment were purchased each year to replace obsolete equipment, in addition to an elimination of the delays in delivery that are likely to be encountered in prosperous years, there would be a leveling out of the peaks and valleys in the business curve. Dr. Julius Klein, former Assistant Secretary of Commerce of the United States, has stated that "it will be impossible to smooth out the oscillations of the business cycle unless we first smooth out these oscillations in the purchase of equipment, and it would seem that this can only be done in response to a definite equipment policy" (1). One author (2) has suggested that replacements be made each year at a rate equal to the amount of the depreciation charged during the year. He further states that such a policy "would smooth out the great peaks and valleys in the production of equipment, would enable the machine user to have modern machines in his plant at all times (provided his depreciation charges are adequate) and would obviate the necessity for large special appropriations for making replace-

ments, for which there is always difficulty in getting authority and which are sometimes difficult to finance. Many companies by establishing and following such a policy in their own plants could realize its profitable results.

G. Who Should Make Replacement Studies?

The only reliable way of knowing when it is economically desirable to replace old equipment is to make a careful and detailed analysis and cost study each time the problem arises and then decide each case on its own individual merits. In other words, estimates have to be made of all the cost factors involved, on the basis of which, alternative pieces of equipment can be converted into comparative costs. But the question arises as to who should make these replacement studies.

Replacement studies and the selection of equipment should not be the responsibility of persons way down the scale of the company organization. Such problems cannot be handled adequately nor intelligently by clerks. Replacement problems are generally of such an importance as to justify the attention and the time of experienced executives, men who are experienced in manufacturing operations and who have a thorough knowledge of the equipment available from equipment manufacturers. Probably, it would be desirable for someone in the company to have as a part of his regular duties the responsibility of keeping abreast of improvements and developments in the equipment manufacturer's industry and then bringing such improvements and developments to the attention of those in authority.

There has been a definite trend away from the selection of equip-
ment by purchasing agents or the purchasing departments, except wherever the purchasing agent is an executive of engineering caliber and training, who could properly be called an equipment engineer. Many companies today maintain a mechanical engineering department under the direct supervision of a chief mechanical engineer, one of whose primary duties is to study equipment already in operation and to make recommendations for increasing its operating efficiency either through changes in methods of operation or through replacements. The actual "leg-work" of collecting cost data on proposed replacements may be delegated to clerks, but the final decision on replacements, based on both tangible and intangible factors, must reside with an experienced executive.

H. Sources of Information on New Equipment.

In order that an equipment-replacement policy may bring to its company the most advantageous results possible, there is an absolute necessity that industrial executives be familiar at all times with the improvements and developments that are constantly being made in equipment. Many companies follow a policy of delegating to a major executive, such as to the factory manager, or to a committee, the responsibility for a knowledge of the new and better equipment available. But how is this factory manager, or committee, to keep abreast of constant improvements and developments? There are several sources of information that would contribute materially to keeping the users of equipment informed of current developments in the equipment builders' industry.

(1) Plant visits. Some companies follow a policy of sending
its executives to other factories to exchange ideas and thus keep abreast of equipment progress.

(2) Machinery expositions. Some companies send their executives to national conventions at which machinery exhibitions are held. In fact, one company has stated this to be their primary source of information and ideas on new equipment since they find it impossible to spend much time listening to equipment salesmen.

(3) Equipment salesmen. This is undoubtedly the most fruitful source of information in the actual selection problem which arises when purchasing equipment. Equipment salesmen themselves are seeking profits through the sale of equipment, and it seems only proper to solicit their help in analyzing some of the problems involved in a replacement study. A policy followed by many companies is to invite the sales engineers of equipment suppliers to submit studies, in detail, or suggestions on equipment where, in the light of their experience and knowledge, an improvement may reasonably be expected that will produce a greater net profit return on investment. It then becomes the responsibility of the potential buyer to check time estimates on the proposed equipment and to ask proof of the suppliers' estimates of speeds, feeds, etc. Other companies follow a policy of submitting drawings and samples of products to salesmen who, in turn, send them back to the equipment manufacturer for estimates on possible rates of production and on the cost of a machine to do the job.

There is no doubt that the user of equipment knows far more about possible applications of new equipment in his own plant than any salesman, once the general characteristics of the proposed new
items of equipment are known. But it is the salesman's knowledge of these general characteristics and his willingness to assist in making cost studies that combine to make him the most important source of information and ideas on new equipment.

(4) Pertinent current literature. (a) The new equipment sections of the technical press. (b) The advertisements of the technical press and trade periodicals.

(5) Suggestion contests. Several companies have found that suggestion contests among its employees are useful for keeping everyone cognizant of the possibilities of the latest in labor-saving equipment.

When the equipment under consideration is entirely new, a good policy would be to make arrangements for one such piece of equipment to be put into the factory on trial. Installation might be in one department only, or laboratory tests might be made on a small scale. One company in the Boston area, before it purchases certain expensive items of equipment, follows a practice either of shipping materials to the supplier's laboratory for trial runs on the proposed equipment or of having the proposed equipment shipped on a trial basis to its own plant where tests are run by the supplier's engineers. By any of these ways the actual performance of the equipment under operating conditions might be checked as to both the definite and estimated figures arrived at in the replacement study or provided by the equipment supplier. This would provide an intelligent basis for final approval or rejection of the proposed equipment.
I. Viewpoint of Equipment Suppliers.

(1) The second-hand market for old equipment.

Most people believe, and they have a perfect propriety in doing so, that equipment obsolescence is very profitable from the standpoint of the equipment supplier. Obviously, when equipment becomes obsolete, new equipment must be purchased, and the sales volume of the equipment supplier should increase proportionately. But this is very often not the case. Users of equipment who deem their equipment obsolete and unprofitable to continue in operation do not always scrap it, but instead very often they sell it to a dealer on the second-hand market for whatever it will bring. The dealer then makes minor repairs, puts on a new coat of paint, and the equipment then comes back on the market to compete with the sale of new equipment. From the standpoint of the seller, the scrapping of obsolete equipment would be much more desirable than disposing of it through a second-hand dealer.

Their approach to the problem would seem to be the education of the equipment users of the fact that discarded equipment which still retains much of its inherent productivity may very easily, and probably will, find its way at a low price into the plant of a competitor. This obviously would tend to cancel to some extent the advantages apparently gained by the replacement. Then too, this equipment in the possession of a competitor would increase the capacity of the industry to produce, which, in turn, would lower prices and reduce the earning power of the former owner. From the standpoint of
equipment users, as well as from that of the equipment sellers, it would generally be better to scrap equipment when it becomes obsolete rather than to allow it in any way to contribute to increasing competition. If the users of equipment can be made to realize this, the position of the equipment supplier can be improved.

(2) Increased productivity.

The equipment supplier is asked to design and build equipment which has an increased productive capacity in order that it will pay for itself in a comparatively short period of time after installation in the plant of the user. But when he develops such a piece of equipment and puts it on the market, is he actually cutting down his own sales volume? For example, if he develops equipment that will do twice as much work as existing equipment, is his possible sales volume cut in half? In a sense, the development of equipment with increased productive capacity may be thought to cut down production in the plant of the builder and thus make it necessary for him to earn a profit on a small production basis; but this is generally not the case. Improvements and developments in equipment also bring about obsolescence, which, in turn, results in equipment replacements. In the end this increase in sales volume as a result of more rapid replacements will more than outweigh any reduction in sales caused by the development of equipment of greater productive capacity. Equipment builders may be expected to continue their improvements and developments in manufacturing equipment.

J. Need for Accurate Cost Accounting System.
The engineer and the operating executive of today is no longer merely responsible for operating and technical achievements of men and equipment under his supervision. His field of activity, and consequently his responsibility, has been extended to include economic achievements as well. It is his job to know when equipment has become obsolete and, generally, to select that equipment which will prove most profitable on the particular operation in question. Therefore, it is quite obvious that provisions must be made in our accounting systems for developing economic and accurate information that will enable the engineer and the operating executive to know the exact conditions that exist with present equipment and to predict results that will follow the adoption of his recommended replacements. This would not be very difficult if adequate and suitable arrangements were made at the outset of business to provide such information. "Manufacturing industries need to develop a science of replacement facts that will reveal not only the problem but the solution". (1)

Obsolescence, undoubtedly, has brought about more retirements of equipment than has physical deterioration. It has been and still is a major problem confronting all manufacturers who use any equipment. Accountants, government officials, and tax experts have all been confronted with this problem, but still no definite means has been devised whereby this problem of obsolescence can be mastered. There is still much to be learned about equipment obsolescence. But there

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is one major approach to the problem that should be undertaken by all managements, and that is, the provision of an adequate cost accounting system. Correct costs will go a long way in distinguishing obsolete equipment, for they will make it relatively easy to determine just how much better the new modern equipment must be over and above the old to warrant a replacement. True costs are indispensable in a replacement study.

Because of the present complexities of business, it is absolutely impossible for industrial executives to physically observe all the things that are going on in their plant. Only from their accounting records and reports can they see all these things at once and arrive at sound business decisions. Decisions involving equipment replacements are no exception. Only through accounting records can the costs of operating equipment be known and compared. When the facts are all available, correct replacement decisions are easy to make. It is when the trouble to obtain these facts is not taken that a decision is difficult to make.

The ease with which provisions may be made in accounting systems to provide the facts allows no excuse whatever for any company not going at this problem of replacement from the standpoint of accurate cost determination and calculations instead of acting under vague emotional impulses, as we do when we get away from cost figures. An accurate cost accounting system which supplies the facts on which to base decisions would transform a great amount of guesswork into practical, measurable factors. In other words, it is highly necessary that companies have a sound equipment policy based on an accurate cost sys-
tem and not merely follow a policy of buying and scrapping equipment empirically. It is realized that no one system of figuring costs will apply to every case. The main point is that users must realize the necessity of figuring costs accurately if they are to determine when a piece of equipment has become obsolete and when it should be replaced by more up-to-date equipment.

Industrial executives are beginning to realize more and more this need for accurate cost information which must serve as a basis for equipment replacement policies. But still there exists in our industrial accounting systems a lack of provisions necessary to develop this cost information. The blame cannot be laid on the accountant. He apparently is satisfied with his present methods in use, and probably rightfully so, and he will continue to use these present methods until such time as those operating executives primarily interested in the effects of obsolescence convince him of the changes that are needed.

A number of companies have attacked this problem of providing accurate cost information on equipment through the use of plant ledger records, either in the form of a book card index or a loose-leaf record. One card, or sheet, is devoted to each machine and piece of equipment in the plant and is usually divided into two sections. The upper section gives full particulars about each item of equipment, showing the machine number, supplier's name, type, size, date purchased, purchased price, installation cost, electrical equipment required, etc. The lower section is used as a detailed cost record, mainly of repairs and maintenance done on the individual item of equipment. If desired, an additional form could easily be prepared to summarize all the individual records for one department into department totals.

Such a plant ledger in use would provide reliable information
on the behavior of each item of equipment and on the economy of its operation. When new equipment is desired, these records could be used as the basis for decisions as to what are the most reliable and economical types of equipment for the job. For example, that equipment which is uncertain in operation and expensive to maintain could very easily be noted from the records. Then too, such records could be used as a check on actual performance after the new equipment has been installed. By carefully recording pertinent cost information and then computing savings over the old equipment, a reliable check may be made on the estimate that served as the basis of the replacement analysis and recommendation.

Some companies even go further than this by establishing in their accounting systems provisions for the determination of the exact number of hours an item of equipment is in operation during each month, or year. For example, the Blanchard Machine Company in Cambridge, Massachusetts has provided a space on their labor time tickets in which machine operators write the number of the machine on which the particular job or operation was performed. The cost department assembles these labor time tickets by machine each month and prepares monthly totals. In such a way, the exact number of hours that each machine in the plant has been used during a selected period of time can be computed. This, in turn, provides a basis for the determination of idle time on each machine, a factor that is considered in replacement analyses. If the records show a particular machine is used only a small number of hours each year, a study would probably be made to determine if its operations could be performed on
other existing machinery in the plant. If they could, the excess equipment might be discarded.

This system has been made possible by a simple procedure of assigning a number to each machine as soon as it is installed and then permanently affixing a small metal plate bearing this number to some conspicuous part of the machine so that it may be easily distinguishable. All the machine operator has to do is to read the number on the metal plate and write it in the space provided on his labor time ticket. The cost department does the rest.
II FUNDAMENTAL COST FACTORS ESSENTIAL TO A REPLACEMENT ANALYSIS.

A. Characterization and Determination.

In any replacement analysis both the existing equipment and the proposed equipment must be considered on its own merits. Whenever the combined savings from the replacement will reduce operating costs sufficiently to justify the additional investment in new equipment, the existing piece of equipment should be replaced. Equipment replacements can generally be expected to increase fixed charges, and it is through its greater productive efficiency which results in a reduction in operating costs that replacements must be justified. Therefore, it becomes necessary that certain fundamental cost factors be determined in order that the economic advantages of one piece of equipment over another might be measured. The cost factors essential to most replacement studies may be considered as falling within one of three cost classifications. These three cost classifications and the cost factors that each includes are set forth as follows:

1. Investment Costs.
   a) First Cost.
   b) Freight and Installation Costs.
   c) Accessory Equipment.

2. Costs of Ownership.
   a) Depreciation.
   b) Interest.
   c) Taxes.
   d) Insurance.
3. Operating Costs.
   a) Direct Labor.
   b) Indirect Labor.
   c) Materials.
   d) Repairs and Maintenance.
   e) Power.
   f) Floor Space.
   g) Supplies and Lubricants.

In some cases it is not necessary to consider all of the above cost factors when making the replacement study. In fact, the cost factors that will be used will depend on the particular method that is used in making the analysis. Some companies prefer to use a method whereby they can calculate either the rate of return on the additional investment or the number of years in which the equipment will pay for itself. Those companies will primarily be interested in that section devoted to the determination of operating costs. But there are other companies which use a method of tabulating total annual costs, and it is these companies that must consider all of the cost factors as listed above.

A following section of this thesis will be devoted to a discussion of the several methods of replacement analysis that might be used, and, it is believed, that a basic understanding of cost determination will provide investigators a better basis on which to decide which of the methods should be used in their particular company.

1. Investment Costs.
In manufacturing companies, the costs of ownership, such as depreciation, interest on investment, taxes, and insurance amount to a substantial portion of the total annual cost of a piece of equipment. These charges arise from the obligations that are incurred when capital is invested in the form of facilities having physical shape and form. The basis of these charges in a replacement study are the valuations which are assigned to machinery, equipment, and, possibly, tools. Therefore, it is important that these valuations be given the consideration which they rightfully deserve.

The question arises as to just what component costs should go to make up the total investment in a piece of equipment which will serve as the basis for the determination of the fixed costs of ownership on the equipment. There is no difference of opinion as to the basis on which the fixed charges for the proposed equipment should be computed, that basis being the total cost of the equipment in-place and ready to operate. This total cost may be referred to as the equipment's in-place value, which is defined as the sum of all costs, known or estimated, that are directly chargeable to the piece of equipment in order to get it ready to produce. The cost in-place ready to operate must therefore be determined by a summation of the following costs, or investments:

a) The capital to be expended for the equipment either through its purchase (the price quoted by the equipment vendor) or through its development and construction if it is to be built by the company rather than purchased.

b) The transportation and installation costs.
c) The investment in any accessory equipment, such as dies, jigs, chucks, fixtures, or any other auxiliary attachments of a permanent nature. Only that accessory equipment which is characterized by a sufficient degree of permanency to be capitalized on the books should be included, not the cost of the many cutting tools and other equipment of similar nature which represent a part of the overhead cost and are charged directly to manufacturing expense. In cases where the motor or other driving agency is a part of or is directly connected to the equipment, the investment in motive power should also be included in the total investment.

d) In some studies, if such an expense can be estimated, it may be desirable to include the cost of testing and perfecting the equipment that is anticipated for a short period immediately following the date of installation.

The total of all these costs, known or estimated for the proposed equipment, will be the total investment or the cost of the equipment in-place ready to operate. This total cost may be used as the basis for the computation of fixed costs of ownership.

The value to be used as the investment in the existing equipment must also be determined. Some companies have followed a policy of using either the original cost or the book value of the equipment, however, for reasons to be discussed in a following section of this thesis, neither of these values could properly be used in a replacement analysis as the amount of the investment in existing equipment.

The only reasonable value that could be used as the basis for
fixed charges of ownership on the existing equipment is the net realizable value of the equipment. This net realizable value may be its scrap value, second-hand value, or that value which, determined through appraisal, the equipment possesses for some other purpose in another location in the plant. Professor J.C.L. Fish (1) refers to net realizable value as "wearing" value, which he defines as an arbitrary term employed to designate the value remaining in any piece of equipment, as evaluated by appraisal of remaining utility through the difference between the net overall value and the scrap value at any time.

The realizable value to be used must be "net", that is, the costs incident to the equipment's removal and disposal must be deducted from the amount to be received for it when sold for scrap or on the second-hand market. But, on the other hand, if any immediate expense for rehabilitation is necessary, this estimated amount should be added to the net realizable value. The total would be an amount which is comparable to the in-place value of the proposed equipment and which may be used as the basis for fixed cost calculations on the existing equipment.

2. Costs of Ownership.
   a. Depreciation.
      (1) Depreciation Base.

      The cost of a piece of equipment in-place and ready to

(1) Fish, J.C.L., Engineering Economics.
operate serves as the basis upon which depreciation charges are to be determined. The cash payment for an asset, plus the costs incurred for transportation, installation, and for accessory equipment should be looked upon as the costs of the entire period during which the asset will render its expected service, this period usually covering several accounting periods. This total cost might also be viewed as a prepaid expense which should be recovered in some orderly manner over the benefited period of years. The only reasonable procedure is to force each year to bear its proportionate share of the total cost of the asset, any other procedure causing one or more years to be excessively burdened with this cost.

(2) Period During Which Equipment Should Pay for Itself.

From the accounting viewpoint, the equipment when purchased is capitalized by being charged in a capital account and then is depreciated at regular intervals over a period of years in accordance with good accounting principles. The customary practice is to estimate the life of the asset, this estimate being based on past performance and experience, and then to charge depreciation periodically into factory costs at a rate determined by this life. Sometimes an allowance is made for the estimated remaining value of the asset at the time it is to be discarded.

Such a procedure may be entirely correct from an accounting viewpoint; however, there should be no connection between the depreciation rate used in the accounting records, or that which will be used if the proposed equipment is actually installed, and the depreciation rate which is used in the replacement study. In a replacement study the depreciation rate should be based upon the period of time in which
the equipment is expected to pay for itself.

This practice, however, is not followed by all companies. Some companies actually attempt to calculate in their replacement studies the number of years in which a piece of equipment will pay for itself. In such practices, depreciation charges are not determined, the procedure being merely to divide the amount of additional investment by the estimated amount of annual savings to be realized as a result of the replacement.

But, if a method (discussed in a following section of this thesis) whereby annual costs are tabulated is used, it becomes necessary to determine the period of time during which the equipment will be expected to pay for itself. Such a decision is a matter of judgement, to be made only by those operating executives and engineers who are familiar with the operation of the equipment in question and with the competitive situation in both their own and their equipment vendor's industry. This period cannot be determined through the use of formulas nor through the most complex mathematical computations.

If there were no such things as price changes, changes in service requirements, or improved alternative methods of manufacture continually being discovered and made available for use, the problem of determining this period of time during which the equipment should pay for itself would not be so great. But such things do take place, making it very difficult to establish any set time. The period of time is dependent on several factors, the most important being:

a) The type of product manufactured.

b) The type of equipment.

c) The extent of the equipment's use.
d) Service conditions.

Equipment which is used for the manufacture of a product subject to frequent changes in design may very rapidly become obsolete, and it becomes necessary that such equipment pay for itself in a relatively short period of time, probably in not longer than a one year period. Consideration should also be given to the possibility of a decrease, or even a stoppage, in demand for the particular product manufactured, which, in turn, could very easily make the equipment obsolete.

The probability of replacement in a few years by more modern equipment or processes greatly influences the determination of this period of time. Attention should be directed to the competitive situation among equipment vendors and the likelihood that new and better equipment will be placed on the market. The probability of replacement in a few years is greater for single purpose than for standard machines, since the latter type permits a more varied change in the design of the product being manufactured before becoming obsolete. Standard machines which are not expensive and which, if necessary, can be used as second-hand machinery might be required to pay for themselves in about three or four years. In some cases, standard machine tools, especially certain very large types that may only be used occasionally, might even be allowed a longer period of time to pay for themselves.

In addition to the factors that bring about obsolescence, consideration must also be given to the anticipated physical wear and tear on the equipment when attempting to reach a decision on the period during which the equipment should be expected to pay for itself. Depreciation may be thought of as being made up of two factors, namely obsolescence and deterioration. In some cases, deterioration due to wear and tear may operate faster than obsolescence, however, it is
the general case where obsolescence due to changes in equipment design and models is controlling. As a rule, deterioration and obsolescence do not bear equally, and it becomes necessary that the one which operates the faster determine the length of the repayment period. An estimate, however, as to the probable extent of wear and tear on the equipment would involve a thorough consideration of the anticipated extent to which the equipment is to be used and of the expected service conditions during its period of operation. A piece of equipment obviously wears out very rapidly through great productive use and under poor service conditions.

Because depreciation is one of the most important items to be considered in determining total costs, the period of time during which the equipment should be expected to pay for itself should have a reasonable basis. If the arbitrary limit that is established is too severe, many advantageous replacements would not materialize. For example, if the limit is assumed to be one or two years when it should be four or possibly five years, the great increase in depreciation charges may very easily discourage plant managers from installing equipment that would have resulted in attractive savings. It is a sound policy, of course, to desire that equipment pay for itself in the shortest possible period of time, but whenever plant managers make this time limit one or two years, it should be questioned whether or not this imposition of such a prohibitive rate of 100 or 50 per cent per year is not too severe. If, on the other hand, the limit is too
great, the occurrence of obsolescence a few years after installation would greatly impair the earning power and capital resources of the company. The limit to be set must lie somewhere between these two extremes. It depends upon many factors, some of which are purely judgment factors.

Probably, the most important aspect of the whole problem of replacement is the ability of the equipment to pay for itself in a reasonable period of time. It is obvious from the above discussion that impending obsolescence should be given primary consideration in the determination of this desired repayment period. Recognition should be given to the fact that equipment as little as two or three years old may very easily become absolutely worthless because of the effects of obsolescence before normal depreciation through physical wear and tear. Therefore, if the capital invested in equipment is to be recovered, it seems that it must be in the early years of the life of the asset. It is a sound business practice to approach liquidation value as rapidly as possible, but care must taken not to impose time limits that are unreasonable.

3. **Salvage Value.**

Sometimes, when determining depreciation charges an allowance may be made for the expected residual value of the equipment when it is expected to be traded in or scrapped. For that equipment which is expected to be discarded within a very few years, an estimate of its realizable value at that time may be of importance. However, it is believed that very little error would be introduced into the problem if no allowance at all were made for an estimated salvage
value at the end of the equipment's "economic life" (1), or, in other words, at the end of that period during which the equipment is expected to pay for itself. The salvage value is never very large as compared with the original cost of the equipment and, obviously, cannot be predicted very accurately.

An estimate of the salvage value of the equipment necessarily has as its basis a series of guesses. First, the estimator must make a guess as to the probable future markets for the equipment and also of the prices which might be obtained upon its disposal either as scrap or to a second-hand dealer. Even the date for this estimated salvage value has as its basis a guess, that of the period of time during which the equipment is expected to pay for itself. It is believed, therefore, that no particular advantage is to be gained by using this factor of equipment salvage value. But, if it should be used, one should be very conservative in his estimates. In a replacement study, it seems desirable and proper to arbitrarily assume the salvage value of equipment as zero.

4. Depreciation Charge.

The annual charge for depreciation to be used in a replacement study may be looked upon as representing that portion of the total investment which the equipment is expected to earn back during any one

(1) Grant, E.L., Principles of Engineering Economy.
year. Both the total investment in the equipment and the period during which the equipment is expected to pay for itself must be determined. The annual depreciation to be charged against the proposed equipment may be computed by dividing its total investment by this predetermined number of years. To determine the depreciation charge for the existing equipment, divide its net realizable value by this number of years. It is believed that this method of straight line depreciation is better for actual use by industrial executives in replacement studies than any of the other possible methods of charging depreciation.

b. Interest.

(1) Return on Investment.

Equipment must not only pay for itself in a reasonable period of time but must also earn for the investor of capital in that particular equipment an adequate return on his investment. The employment of capital in any venture implies a charge for the use of that capital and creates an obligation upon the venture to bear the cost of the capital invested in it. Capital invested in equipment is no exception. An obligation is created at once for that equipment to earn an adequate return on the capital invested in it, this return in addition to the recovery of the original investment through the depreciation charges.

Even though interest on the investment is not allowed for income purposes on our accounting records, it nevertheless is a factor that must be considered in a replacement study. The plant manager who invests capital in equipment may be compared with those trustees and financial executives who deal in the purchase and sale of corporate
securities. By the same theory that trustees and financial executives dispose of securities that fail to earn a satisfactory return, plant managers should discard that equipment which fails to earn a satisfactory return, whenever it is possible to replace it with equipment that will earn a greater return. In practically every replacement study that is made, the several alternative pieces of equipment that are involved will require different capital investments. Consequently, unless due regard is paid to the different amounts of capital invested by charging a reasonable rate of interest for the use of that capital, the replacement study will give a result too favorable in support of that equipment which requires the greater amount of capital investment. Interest on investment, therefore, must be considered in a replacement study, and the problem arises as to just how great a rate of return the equipment should be expected to earn.

(2). Risk Involved.

An adequate return may be considered as the reward due the investor of capital for assuming the risks involved in making his investment. Where the risks of business are great, a high rate of return must be promised in the particular venture in order to attract the necessary capital. Whether investments are made in securities or in manufacturing equipment, the rate of return that will be expected will vary with the risks involved in that investment.

Some companies follow a policy in their replacement studies of charging the investment in equipment with merely a simple interest rate, say of 6 per cent; however, it is quite doubtful if these companies, or anyone, would consider investing its money in any other
venture that promises merely a simple interest return. The choice of an interest rate to be used in a replacement study is a matter to be settled by an arbitrary decision based upon past experience and executive judgement of future as well as present circumstances. Attention must be directed to the degree of risk that is involved whenever capital is invested in manufacturing equipment, as it is this degree of risk that is inherent in the particular investment that should serve as the basis for a decision on the rate of return that should be expected. The degree of risk involved will vary among different types of equipment and with the nature of the product to be produced on the particular equipment.

Because of the greater probability of sudden obsolescence, single-purpose equipment would demand a higher rate of return than standard equipment. A concern which has stable production of a product not subject to frequent design changes may deem a 12 per cent return on investment in equipment entirely sufficient, while those concerns whose product designs are susceptible to rapid change may indeed be wise in insisting on even a 25 per cent return.

Having given careful consideration to all the risks incident to the particular investment in question, a decision must be made as to the rate of return that should be expected. Professor Paul T. Norton, Jr. proposes "that in making a replacement study the capital investment required for each equipment should be charged with that rate of return which would make the investment attractive when consideration is given to the risks that seem inherent in the particular investment" (1).

This means that the rate of return to be used in a replacement study is that rate of return for which the investor would be willing to invest his capital in the particular equipment.

Having decided upon the rate of return to be used, it then becomes necessary to determine the interest cost to be charged against each item of equipment in the replacement study.

(3) **Computation.**

The interest cost is based upon the amount of investment capitalized as an asset and carried on the accounting records. Since the investment each year is decreased through depreciation, there is an annually diminishing cost of investment on which interest charges must be based. Either the average investment at the full rate of return or the initial investment at an average rate of return may be used. However, it is believed that the latter method is most common and the easiest to apply in a replacement study.

The average annual interest cost may be calculated by dividing the number of years during which the equipment is expected to pay for itself plus 1 by this number of years, multiplying the quotient by one-half the rate of return expressed as a decimal, and multiplying the product by the total investment. Under uniform depreciation for n years, the average annual interest rate becomes:

\[ \frac{1}{2} A \cdot \frac{n+1}{n} \]

A = Rate of return

n = Number of years during which the equipment is expected to pay for itself.
This value will decrease from \( A \) for one year, and will approach \( A/2 \) as \( n \) becomes greater. For a life of two years this value is \( 3A/4 \); for three years, it would be \( 2A/3 \). The average rate of return, as computed above, when multiplied times the original total investment in the proposed equipment will provide the interest cost to be used in the replacement study. For the existing equipment, interest cost is computed on the basis of net realizable value instead of original cost.

c and d. **Taxes and Insurance.**

In a replacement study, two other annual cost factors falling within that classification designated as "costs of ownership" must be charged against each piece of equipment in question. These are the charges for taxes and insurance, which are derived from the application of a fixed rate upon a portion of the total investment, the rate being set arbitrarily by tax laws and insurance policies. The annual tax bills will readily supply the amount of taxes, which usually ranges between one and three per cent of the assessed value of the equipment. All property taxes, taxes in the nature of license fees, if any, and any other taxes levied on the assets should be included. Also, the company may be carrying several kinds of insurance, such as fire insurance, use and occupancy insurance, or insurance as a protection against the damage of explosions and floods. The cost of insurance can be determined from the insurance policies held by the company.

In a replacement study, the costs of taxes and insurance must be
charged directly against each piece of equipment. This is done on the basis of capital investment. It is believed that the logical way to apply these costs in a replacement study is to determine from the tax bills and insurance policies the percentage these costs bear to the amount of investment in the equipment. This percentage must then be corrected in the same way as previously described for the interest rate, in order that the average annual cost with diminishing investment might be computed. The percentage thus determined when multiplied by the total investment will result in the amount of annual cost to be charged against the proposed piece of equipment for taxes and insurance. The charge against existing equipment is computed by multiplying this percentage by the equipment's net realizable value.

3. **Operating Costs.**

a. **Direct Labor.**

Direct labor, when expressed as a yearly cost may be expected to vary with the quantity produced; therefore, the first step in the determination of labor cost is to note the yearly quantity of production that is desired or needed to meet sales estimates. Such information could be obtained from the company's sales and statistics departments or based on various governmental publications. Consideration must also be given to finished goods inventories on hand, and to several other factors, the discussion of which are beyond the scope of this thesis.

Then the actual time on the existing equipment and the estimated time with the proposed equipment to provide this desired quantity of production must be calculated. All time figures should include set-up time, or the period necessary to prepare the machine for operation,
and should probably be based on approximately a 48-minute hour to allow for the inevitable delays in plant operations. This 20 per cent allowance for downtime is only an approximation. It should be estimated by the production manager or other operating executives who are familiar with production operations. The actual determination of operating times would necessitate that either past company records on the existing machine be available or that a time study be made. Time data for production on the new machine could probably be obtained from the machine tool builder upon request. His sales engineer should be glad to secure and provide this information.

The other factors needed for the calculation of direct labor cost are the number of operators that will be required on each piece of equipment and the wage rates per hour for each operator. It is quite possible that the new machine will result in a reduction in the number of operators required and, also, in some instances, permit the substitution of machine operatives for skilled craftsmen, thus lowering labor costs by the change. Wage rates per hour could be secured from payroll records, or from the accounting department.

Summarizing, the formula for computing direct labor costs per year on equipment is as follows:

\[
\text{Direct labor cost} = \text{Operating hours per year on machine times Number of operators on machine times Wage rates per hour.}
\]

Where wage rates vary among the different operators on the machine, the actual value of the labor on the machine must be calculated independently and then multiplied by the operating hours per year.

For those companies which do not elect to use a total annual cost
basis of comparison in their replacement studies, but deem it sufficiently accurate for their purposes to attempt to justify a replacement on labor savings alone, the preceding method could also be used. The difference between the direct labor cost on the existing machine and that on the new proposed machine, costs having been computed as explained above, would be the dollar saving in direct labor. This amount if divided into the total investment in the new machine would result in an estimate of the number of years in which the machine would pay for itself.

b. **Indirect Labor.**

As a rule, equipment replacements will not result in very much change in the indirect labor cost. However, under some circumstances, it is quite possible that the effects of equipment replacements on the jobs of such men as sweepers, cleaners and oilers, inspectors, time-keepers, truckmen, and clerical workers may cause indirect labor costs to be increased or decreased. A realization of the possible effect of new equipment on indirect labor is important, and it definitely seems that a careful analysis of the major individual items that make up indirect labor cost in order to determine just what indirect labor cost might be expected to be with each piece of equipment would be justified.

Many companies which expect a reduction in direct labor or materials costs as a result of equipment replacements merely assume that indirect labor costs also will be reduced. Consequently, they make no examination of specific indirect labor cost items. A great weakness of the equipment policies of many companies is that they contem-
plate charging indirect labor cost at a percentage rate applied on
direct labor cost. Such a practice is not tenable when consideration
is given to the fact that various kinds of equipment call for widely
varying investments and operating expenses, some of which are not re-
lated to direct labor at all. The main objective of many equipment
replacements is to reduce either production time or direct labor
cost, and that method of estimating indirect labor as a percentage
of direct labor cost is very apt to charge a smaller amount to the
superior equipment, even though this equipment might actually be a
source of higher indirect expenses. Indirect expense is made up of
items derived from some service supplementary or complementary to
actual production and need have no necessary relationship to direct
labor costs. Therefore, it seems that the assumption that indirect
labor will increase or decrease in the same proportion as the expected
increase or decrease in direct labor cost is fallacious, and that the
only accurate way to determine the effect of equipment replacement
on indirect labor is to examine its effect on each specific indirect
labor cost item.

Another method that is used by some companies is that of reducing
overhead charges to an hourly basis, overhead cost not being broken
down into its elements. In such cases an overhead charge per hour,
say $2.00, is established as an average for a particular department.
Then, when the new equipment would result in a saving of a certain
amount of time, the assumption is that this equipment should be given
credit for each hour saved at the rate of $2.00 per hour. Such an
assumption is also fallacious. For example, the application of the
same overhead per hour to a machine costing $5,000 and to another costing $50,000 would obviously give misleading results. One author (1) states that "a differential overhead based on the capital invested in the individual piece of equipment under consideration is the only accurate way in which a true picture of the case can be arrived at".

However, in a replacement study, it is believed that overhead should be broken down into its elements and each element analyzed separately. Unfortunately, because of an equal necessity for prorating to the product a number of other indirect factory expenses, present cost accounting systems do not usually develop as burden an amount covering simply the indirect cost of labor. The factory burden account covers many items, and if the cost of indirect labor alone is to be determined, it becomes necessary to break down the burden account.

J.A. Shepard and C.E. Hageman (2) have suggested a simple method of developing the exact indirect labor pertaining to a department, or, to a piece of equipment, in case extreme exactness is desirable. They state that "indirect labor may be developed from the same accounting which develops factory burden, values of the items which are chosen to compose the indirect labor being carried to an extra column so as to form a separate total". They further state that "a method which has been found convenient for developing indirect labor consists in pro-

viding additional columns on the analysis sheet so that items may be transferred, as far as desired, from the regular burden account to these extra columns to form the indirect labor account".

The question of whether such a refinement in the accounting records is desirable must be decided by each particular company. It is quite possible that the extra clerical labor and expense involved in such a procedure will more than outweigh the value of this greater degree of accuracy in developing indirect labor cost. However, if the additional cost is not too great, such a method of providing a separate column in the accounting records to show the account to be charged is ideal for developing the indirect labor cost chargeable to the existing equipment. This cost would also serve as a basis for estimating the indirect labor cost to be charged against the proposed piece of equipment.

c. Material Cost.

To evaluate the expected cost of material, it is necessary to estimate accurately either the number of hours the machine will work during the period in question or the quantity of production required of it. Computations should not be made on the basis of possible production of the equipment operating at full capacity, as such a basis will provide misleading results. Material costs should be based on the actual expected number of pieces to pass through the equipment, consideration being given to rejections. Anticipated rejections should probably be expressed as a percentage based on past experience and future expectations. In other words, material costs should be expressed
as the monetary equivalent of material actually needed for the finished
product plus an allowance for spoilage and waste material which is ex-
pected to accumulate during the year. The following formula
is suggested:

\[ M = N \times D + 0.02 \quad (ND) \]

\( M \) = Material cost per year.

\( N \) = Number of units of finished product per year.

\( D \) = Cost of material actually needed per unit.

0.02 = Percentage allowed for spoilage and waste (to be based
on past experience and future expectations).

If it is estimated that the proposed equipment will result in a
smaller percentage of waste material or number of units failing to
pass inspection, there would be a reduction in material cost. Other-
wise, material costs would generally be the same for each piece of
equipment in the replacement study, provided the same material would
be used in either machine.

Savings in material cost through equipment replacements may even
be greater than savings in direct labor in some cases and thereby be
the most important factor that determines whether or not the replace-
ment should be made. For example, one company estimated that with new
equipment a definite recovery of a chemical could be made, over and

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(1) Vorlander, H.O., and Raymond, F.E., Economic Life of Equipment.
    Transaction, American Society of Mechanical Engineers,
    MAN-RP-54-2 (1932)

(2) Richards, E.M., To Buy or Not to Buy Equipment.
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above that recovery currently realized on existing equipment. The value of this recovery was considerable, which would enable the equipment to pay for itself in a very few years. Another company was faced with the problem of whether or not it should replace an existing piece of equipment used for the distillation of gin by a vacuum still. Its replacement study revealed that a considerable saving in gallonage during distillation would be realized should the replacement be made. Maximum temperature during distillation with the proposed equipment would be 130° F., whereas with the existing equipment the temperature often rose as high as 212° F. In either of these cases cited, any saving that could be realized in labor would be considered as so much extra advantage. The saving in material would be the deciding factor.

d. Repairs and Maintenance.

In a replacement study, repairs and maintenance expense should be looked upon as including two major cost factors: (1) cost of repair materials, or parts, and (2) the cost of repair labor. This expense should be viewed as that which is necessary to keep the equipment in good running order, so that its productive capacity, or its original state of efficiency, does not decline. Unfortunately, similarly to the treatment of indirect labor as discussed in a previous section of this thesis, present cost accounting systems usually treat this expense as an overhead item and do not develop it for each individual piece of equipment. Such a treatment may be entirely correct from an accounting point of view, but because of the possible magnitude and importance of repairs and maintenance expense, it must
be given separate consideration in a replacement study.

The charge against existing equipment must be based on past experience with the piece of equipment in question. Therefore, it would seem desirable, in many cases, for companies to devise an accounting system, fitting their own particular needs, whereby repair and maintenance expense may be developed by machine or other individual piece of equipment. In addition to the need of such records when making replacement studies, these records would also be of great assistance to the maintenance department in their planning machine overhauls.

Costs must be collected for both repair material and for repair labor. Therefore, the key forms to be used in such a system would be the labor time ticket and the material requisition, both having a space provided for writing in the number of the machine on which the repair was made. A summary of labor costs and the cost of repair material by machine or piece of equipment might then be developed in the cost department every month. If such a system were in use in a company, the problem of deciding just what annual maintenance charge should be made against an existing piece of equipment in the replacement study would be relatively easy.

The cost of repairs and maintenance to be charged against the new proposed piece of equipment must be estimated, and it is very probable that this charge will be less than the annual charge against existing equipment. Consideration must be given to such factors as the expected machine load, care of the operator, quality of repairs, and the specific wear that comes from any anticipated special use. In estimating repair and maintenance costs, it might be desirable to
assume that a certain limited amount of machine repair is necessary and legitimate. One company specified this amount of repair time on the basis of four hours per month for every $1,000 initial cost of the machine. (1)

(e) **Power.**

The cost of power in a company may consist of either the amount paid to power companies for power purchased, or it may include all the accumulated expense incurred in generating, distributing, and transmitting power when the company operates its own power plant. In either case, the cost of power, which is usually treated as an item of overhead, must be allocated to individual machines and pieces of equipment when a replacement study is made.

"The basis for distribution of a joint expense should be that factor of which the expense is most nearly a variable." "Thus the power costs are a variable of kilowatt-hours of energy consumed. Hence the distribution of power costs among the departments (machines) is on the kilowatt-hour of consumption basis." (2) Likewise, steam expense may be allocated on the basis of the number of thousand pounds

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of steam used, and compressed air on the basis of cubic feet.

It seems that the logical way to determine the annual power-
consumption charge for any piece of equipment would be to first
determine the amount of power consumed per hour, which would be based
on actual tests made on each type of machine under working conditions,
or on estimates, where such tests cannot be made. This amount per
hour, when multiplied by expected operating hours per year and then
times the cost per unit-hour would give the annual power cost of oper-
ating the machine or piece of equipment in question. Although power
costs may not be different between the existing and the proposed machine
in all cases, this estimate should involve no great difficulty and
should be made.

(f) Floor Space.

Because different equipment may require different amounts of
floor space in the plant, it becomes desirable to include the cost
of floor space in a replacement study. If the premises are owned by
the company, this factor is developed out of the annual expense of pro-
viding and maintaining the land and buildings. In other words, this
annual rental expense is composed of three classifications of rental
costs:

1) Fixed Charges (1)

Fischer, N.T., Shop Expense Analysis and Control
The Engineering Magazine Co., N.Y. (1920)
(a) Depreciation, insurance, taxes on buildings and permanent fixtures.
(b) Interest on investment in grounds, buildings, and permanent fixtures.

(2) Maintenance.
(a) Repairs and upkeep of building and fixtures.

(3) Service.
(a) Light, heat, and ventilation.

As a matter of fact, in a replacement study, it should include practically all those overhead cost items which are not included in any of the other cost factors.

If, on the other hand, the premises are not owned by the company, the rental paid to the landlord is part of the cost of space occupied. In those cases where the building is rented, the total annual rental expense should include, in addition to the annual rent paid, the annual maintenance and service costs, which are not included in the amount paid to the landlord. This total rental charge would be treated in the same way as the cost of floor space that is computed when the premises are owned by the company.

The common practice is to prorate this total expense to the different departments, and to the different machines, on the basis of floor space occupied, the unit of distribution being the square foot. Therefore, it becomes necessary to determine a rate per square foot. This rate would be computed by dividing the total rental expense per year by the total number of square feet of floor space in the plant, which includes both occupied and unoccupied areas. This procedure would re-
result in a rate per square foot which could be used to allocate the
cost of floor space to each piece of equipment that is involved in
the replacement study.

The area occupied by the piece of equipment should be care-
fully measured and should include not only the projected area for the
equipment, but also any additional space necessary for its proper operation
and maintenance. Then, the proportionate cost of floor space can be
charged to each piece of equipment on the basis of this area occupied
at the established rate per square foot. Therefore, where the pro-
posed equipment requires a greater or lesser amount of floor space,
the floor space charge in a replacement study might be different for
each piece of equipment.

It is quite possible that operations may be consolidated by in-
stalling new equipment and that other work may then be performed in
the extra space thus made available. If this is the case, the new
machine should definitely be credited with a saving in floor space.
It would be a good practice to follow, however, "not to credit a pro-
posed machine with any potential saving in floor space unless the space
that is released can be used for some other productive purpose". (1)

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Norton, F.T., Jr., The Selection and Replacement of Manufacturing
Equipment.
Bulletin of the Virginia Polytechnic Institute. XXVII,
No. 11 (Part 1) September (1934)

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Other authors (1) advocate that "if less space is occupied, the burden of the remaining unoccupied space left over from the previous equipment should become a general charge against management until such a time arrives that it can be properly utilized". In theory this latter point of view may be entirely correct. However, the former would undoubtedly give a better picture of the replacement situation.

Because of the present high cost of plant construction, most companies realize the importance of a saving in floor space. One company stated that floor space to be occupied is a very important consideration in their design of equipment because of the limited amount of space available in their plant. Another company with insufficient floor space available is forced to subcontract a portion of its manufacturing. This plant manager states that if he could replace a number of his machines with machines of greater capacity and occupying less floor space, he would not have to subcontract his work. He could do this work in his own plant at less cost. Such a saving may be looked upon as one of the intangible factors that influence the replacement decision.

g. Supplies and Lubricants.

This cost factor should include the cost of all indirect materials and lubricants not used directly in the product itself, but used in and about the piece of equipment in question. The amount to

be charged against the proposed equipment must necessarily be based on an estimate of the quantity to be used. The charge against existing equipment could be developed from adequate past accounting records.

Accounting for supplies and lubricants that are used necessitates regular inventory records and a complete control over all supplies and lubricants released from stores. Some form of a supply requisition, which provides a space for the equipment to be charged, should be used. If this is done, the stores clerk, or the cost department, could very easily compute the cost of supplies and lubricants to be charged against each piece of equipment or a particular machine.

3. Degree of Refinement in Calculations.

The economic selection and replacement of equipment is undoubtedly one of the most important problems facing modern management, and, of course, an intelligent and highly accurate replacement study is desirable. But, it will generally not pay for investigators to be finically scrupulous in their replacement analyses and calculations nor in their search for minor and uncertain differences in economic performances between alternative equipment. At the time that the replacement study is made neither the economic life of the equipment, the actual rate of depreciation and obsolescence, nor the average annual cost of labor, power, maintenance, etc. are definitely predictable. Even the basic data employed in the economic evaluation of the alternative pieces of equipment, therefore, may have in them a probable error of considerable magnitude. Because of this probable error in data, it will not pay for investigators to go to the utmost in the refine-
ment of calculations and analyses that these errors do not warrant. The degree of refinement in making calculations is a matter to be decided by the particular company making the replacement study, and it is dependent upon the availability and accurateness of basic data and of estimates.
III. THE REPLACEMENT ANALYSIS.

A. General Considerations.

1. Equal Expected Service.

To provide a rational basis for a decision on equipment replacements, some method must be devised for evaluating and determining the relative economic advantages of one item of equipment over another. Regardless of the method that is to be used, it is essential that the investigator realize that the economic superiority of one item of equipment over another can be properly determined only on the basis of equal expected services. In other words, all cost estimates and cost comparisons must be based on the same amount of service, even though there may be several alternative pieces of equipment involved in the replacement analysis. If costs on the equipment being compared are computed on the basis of unequal amounts of service, it is quite possible that one of the alternatives will be granted an advantage which may not accrue to it in the future.

The probability is great that the proposed new equipment will provide a greater capacity than that available on the existing old equipment. But, on the other hand, the old equipment may be entirely adequate to provide the desired amount of service, and there may be no need for additional capacity. In such cases the extra potential productive capacity of the proposed new equipment should be regarded as an irreducible factor in its favor (1), and by no means should it be included in the actual annual cost calculations of the replace-

ment analysis unless this extra capacity is actually to be used. Such a potential capacity is of great importance, however, and should definitely be given consideration as one of the intangible factors that may have a deciding influence on the ultimate replacement decision.

In many cases there may be also a change in the amount of service required, such as a required increase in production to meet increased sales estimates. The capacity of the existing old equipment may be inadequate to meet this desired increase. Under such circumstances, the replacement study will very often involve a cost comparison between a proposed piece of equipment of the desired productive capacity and the existing equipment plus supplementary equipment, the combination of which would provide the desired capacity. But will such alternatives as these upset this basis of an equal expected service? Definitely not; the service desired of each alternative is still the same even though it may have been increased in amount.

2. Cost Omissions.

Many authors and industrial executives suggest that costs and revenues which are unaffected by the choice of equipment may be omitted from the replacement analysis. Such reasoning is absolutely correct. The objective of a replacement study is to determine the possible economic superiority of a proposed piece of equipment over the existing equipment. To do this, we need only to formulate a relationship between the two items of equipment so that the differential between each individual cost characteristic is exposed. If this is done, all the significant cost factors will be included. In other words, the main problem of a replacement analysis is to determine just
how much costs would be changed by installing and using the new equipment instead of continuing the old in operation.

Even in the annual cost method of comparison (which is discussed in a following section of this thesis), where it is apparent that some costs will be approximately the same for alternative pieces of equipment, it is generally desirable to omit these particular cost factors in order to save time. If this is done, the difference between the annual costs of alternative pieces of equipment will not be changed, but the annual cost chargeable to each piece of equipment will no longer represent total annual costs. Total annual costs are not needed however where the purpose of the study is merely to determine whether or not equipment replacement is desirable.

Therefore, in the light of the above reasoning, it is generally desirable to omit from the replacement analysis all those cost items which are neither increased nor decreased by the installation of new equipment. In some cases several overhead cost items may not be affected at all by the replacement of obsolete equipment. Then too, there may even be some expense items which are directly related to the operation of the old and new equipment, such as the cost of power, materials, etc., that do not differ sufficiently to warrant their inclusion in a practical replacement analysis intended merely to determine relative costs and savings.

3. Individual Merits Govern.

What industrial executives want to know is this: How much actual money will be saved by replacing existing equipment with a proposed piece of equipment? In answering this question, it is absolutely necessary that each installation of equipment be considered on its
own merits and that a replacement be made only whenever the combined savings from the replacement will reduce operating costs sufficiently to justify the additional investment. It is necessary to investigate each particular proposal and to make a careful analysis of the work it is capable of performing with regards to cost, quality, the fatigue factor, handling to and from the machine, etc. If the same type of study is made for the existing equipment, its performance could be intelligently compared with that of the proposed equipment, thereby determining which piece of equipment is capable of doing the work most efficiently and economically.

4. Variation Among Different Concerns.

Replacement policies will not be the same in all concerns but will vary according to the type of industry and the class of products manufactured. For those concerns with highly specialized equipment or which experience radical yearly changes in the designs of products, the standard of time in which the equipment must pay for itself required to justify replacements will be comparatively short.

Also, there are those concerns which are subject to violently fluctuating demands of customers. Such concerns often follow a policy of retaining older machines in their plant, even after replacements have been made, in order to meet the needs of the coming periods of increased activity. Executives of such companies believe that the profits realized from the greater possible production of these periods of increased activity will more than offset the losses of carrying the equipment. In addition, they sometimes look upon this obsolete
quipment as representing excess capacity which is not costing them anything, since in many cases it has already more than paid for itself. Therefore, they believe that they are not penalizing themselves by having this equipment lying around idle in their plant. This may be a fairly logical form of reasoning in some cases, but it should always be remembered that antiquated equipment standing around may be taking up valuable floor space and may have a bad influence upon shop morale.

In some concerns the economic advantages of one piece of equipment over another may be subordinate in importance to other considerations. For example, in those concerns where a precision product is manufactured, accuracy of the producing equipment may well be the controlling factor which determines whether or not it is desirable to make proposed replacements. In other concerns, quality of product may be the controlling actor in a replacement analysis. For example, one company installed a new $14,000 air cleaner in its plant to take the place of an existing cleaner. This new equipment was neither expected to increase productive output nor reduce operating expenses. Its investment was justified solely by the assurance of a better quality of product. The ease with which replacement studies can be made will also vary among different concerns. In those cases where the equipment is part of a production line and works continuously on the same product, the replacement study is relatively easy to make. But where the equipment is part of a jobbing shop, the decision as to when to buy and what to buy is much more difficult because the purchase must be made without knowing exactly what the new equipment will be required to turn out the next year, or even the
next month. A replacement study under such circumstances would necessarily have to be based on several selected typical operations that are performed, an estimate being made of the costs of each of the several operations if performed on the existing equipment and if performed on the proposed equipment.

5. **Flexibility in Policies.**

It is absolutely necessary in establishing an equipment policy that industrial executives be aware of and prepared to meet changing conditions that will affect equipment policies. No policy can remain inflexible in a changing business economy such as this experienced in this country. One author has stated that "a rigid equipment policy is quite as untenable as an unchangeable standard" (1). In a sense, he is absolutely correct. An equipment replacement policy must definitely be adjusted to conditions as they change.

Most companies have begun to realize this necessity of flexibility in equipment policies. For example, as far back as the year 1931, H.P. Bailey, of the Warner and Swasey Company in Cleveland, Ohio stated that a "general equipment policy must be flexible enough in its application to meet changes in activity of different departments due to changing economic conditions" (2).

**B. Common Methods in Use.**

Most companies have accepted the principle that it actually pays to replace old equipment with that which is new and up-to-date. However, the methods of making replacement analyses vary among different companies and very often are dependent on the individual idiosyncrasies of the engineers and operating executives on whom this problem of replacement falls. But it would be safe to say that practically all companies follow either one or both of two common methods: (1) Determination of the number of years required for the new equipment to pay for itself, and (2) Determination of the rate of return on the extra investment.

**Repayment Period.**

A company may follow any one of three policies in allotting a period of time to a piece of equipment in which it must pay for itself.

a) No definitely established period. Some companies refuse to set a definite limit, taking the standpoint that each purchase must be made strictly upon the merits of the case.

b) Varying periods depending upon the particular kind of equipment involved. For example, D.S. Linton (1) of the Rotor Air Tool Company has stated that a part of the replacement policy of this company was as follows:

1. Buy new machine-tool equipment where the period of repayment is four years or less.
2. Replace productive equipment, such as tools, jigs, and fixtures, where the period of self payment is two years or less.

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c) Fixed time period. In view of the many factors (discussed in a preceding section of this thesis) which should influence the length of the required self-payment period, it is generally very difficult to set up some arbitrary limit within which the equipment must pay for itself. A company which does have a definite fixed period when considering the purchase of equipment for the manufacture of its regular output would vary this period, however, where the equipment is needed for contract jobs.

Most companies require that equipment should pay for itself in from two to five years. However, in many cases, depreciation charges that are used in the replacement analysis are still calculated at the common rate of 10 per cent per year instead of at a rate of 20 to 50 per cent per year. Such a practice should not be followed. A greater return on the investment will be shown with the 10 per cent depreciation, but, on the other hand, a greater book value of the equipment will have to be written off if the equipment becomes obsolete within the two to five year period. A more extensive discussion of this problem was set forth in a preceding section on depreciation.

2. Rate of Return.

Many companies prescribe that new equipment must earn a certain percentage return on its investment in order to justify the replacing of old equipment. For example, the Warner and Swasey Company in 1931 had as a part of its equipment policy a provision which called for the purchase of new equipment which, under existing shop conditions, would return a net profit on the investment of 20 per cent or more per year(1).

As a matter of fact, this method of requiring that equipment earn a certain rate of return on the investment is no different from that method which requires that equipment pay for itself in a certain length of time. If we require that equipment earn a return of 20 percent on its investment, we are in effect requiring that it pay for itself in five years. The rate of return on the investment may be calculated by dividing annual savings by total investment. If, however, we invert the equation, the quotient will be the number of years in which the equipment will pay for itself. Therefore, since there would be no difficulty in doing so, many companies have a policy of computing both figures in order to get a better picture of the replacement problem.

C. **Common Fallacies in Replacement Studies.**

There are still today a number of companies, which point with pride to their adequate and intelligent replacement policies, that do not realize that they are committing serious errors in the actual conduct of their replacement studies. From my observation of a number of actual replacement studies that have recently been conducted, and from a research into the published literature on this subject, I have noted a number of common errors that are being committed. Several of these errors have already been discussed in preceding sections of this thesis, such as:

1. The **calculation** of overhead costs, or any one of its elements - indirect labor, as a percentage of direct labor, (discussed in Section on Indirect Labor).
(2) The consideration of the extra potential capacity of proposed equipment as a tangible factor in cost calculation, even though this extra capacity is not likely to be used. (Discussed in section on Equal Expected Service).

(3) The crediting of a proposed piece of equipment with a potential saving in floor space, even though the space released is not to be used for other productive purposes. (Discussed in section on Floor Space).

(4) The use of the original cost or the book value of existing equipment as the basis for the fixed charges to be used in the replacement analysis. (Mentioned in section on Investment Costs).

If the original cost of existing equipment is used, it seems quite obvious that we would be requiring the equipment to earn a return on a part of its original cost which has already been recovered through depreciation. Such a procedure is definitely misleading. The replacement study will unduly favor the proposed new equipment.

The same reasoning may apply to the use of book value as the basis of fixed charges on existing equipment, although the error that results would not be quite so great. If we use book value we are implying that this is the actual value of the equipment, which is generally not the case.

In addition to the above errors that are commonly committed, there is another which necessitates particular mention, namely, that of charging the unamortized value of existing equipment against the proposed new equipment. Unamortized value may be defined as the difference between the present book value and the net realizable value of the equipment.
From the standpoint of the accountant, there is often some objection to rendering worthless by replacement a piece of equipment which is still carried on the books at a considerable value. It is often argued that the capital loss (unamortized value) which seems to occur at the time of replacements is caused by the replacements, and that any such loss should be charged against the new equipment.

But why should we burden new equipment with the results of previous errors that have been committed? Any difference between book value and realizable value represents an over or under statement of the equipment's life in estimating the depreciation rate at the time the accountant's depreciation schedule was set up. Its amount is due solely to an erroneous decision as to the economic life of the equipment and consequently to the error in the depreciation rate that has been used. It represents depreciation which has actually occurred during the equipment's life and which should have been charged off to products. In the light of the above reasoning, it seems that if we make new equipment bear the burden of the unamortized value of the old equipment, we are, in effect, basing present decisions on previous erroneous decisions. Such a practice cannot be justified.

From a true engineering and economic standpoint, the value at which the old equipment is carried on the books should not be considered in a replacement analysis. What we are merely trying to determine is whether or not the operating savings to be effected will justify the new capital investment. The book value, and consequently the unamortized value, of equipment is irrelevant in the actual replacement analysis.

But how should the accountant charge off this unamortized value
of existing equipment when the replacement is made? There are several alternatives:

(1) Charge it directly to the Profit and Loss account. When the asset is discarded, its original cost is credited to the capital asset account. The amount of reserve which has been accrued on it is debited to the reserve for depreciation, and any balance of the cost less the proceeds from the sale of the asset as scrap or to a second-hand dealer is debited to the Profit and Loss account, which might be captioned, 'Loss on Equipment Retirements'. If this procedure is followed, the old asset will be completely and properly removed from the books.

Some companies follow a practice of charging this unamortized value of old equipment to the factory overhead expense incurred during the year in which the retirement occurred. In other words, it is charged directly to the operating expense of the current period in the same manner as the depreciation charge. If this can be done without distorting the results of that particular year, it may be desirable to get rid of the unamortized value in such a manner. But generally, this cannot be done. The amount is often large enough to affect the operating results materially. Then too, many companies use their accounting records for comparing results by months, or by years, with the preceding periods, and to introduce a charge of this nature into operating expenses would obviously invalidate the value of any comparisons of which this particular year is a part. It is believed therefore that a better policy would be to show the net profits before this charge and then to deduct it from Profit and Loss as a special item. It would be extremely undesirable to allow this amount of
unamortized value of existing equipment to be included in the computation of current costs to be used for price-making purposes.

(2) Charge it to surplus. The surplus amount of the company would be composed, in part, of undistributed return which accumulated because depreciation charges had been understated in the past. This, obviously would have made the return unduly great.

(3) Charge it to a replacement reserve. Such a reserve must have already been set up, a portion of the profits of the company having been properly earmarked for the purpose of providing against the losses due to replacements before the original cost of the equipment had been covered by normal depreciation.

D. Use of Formulas.

Numerous attempts have been made to derive formulas that may be used in replacement studies, a great many of which have been published. Even though there is a growing tendency among industrial executives to recognise the inevitability of continuous needed change in equipment policies, there still are many companies that cling to complex and rigid replacement formulas.

Of course, there are some advantages to be derived from the use of formulas, where the formula is correct and not too complicated to be used by operating executives. Formulas make it possible to delegate routine problems of the replacement study to clerks, who otherwise would be of very little assistance in the actual replacement analysis. Then too, a formula may have an advantage in preventing the omission of important factors that are essential to the replacement analysis.
But, on the other hand, executives should be aware of the shortcomings inherent in the use of formulas. Very few of the formulas that have been developed have proven entirely suitable for handling the replacement problem. Many of them are too complicated or too difficult to actually be applied by plant engineers and operating executives in actual practice. Professor Rautenstrauch has stated that "a formula containing every conceivable factor may be theoretically correct, but of little or no practical value because it includes certain items difficult to determine and not practically required" (1).

There may actually be a different formula for each kind of machine, but still there is almost always something missing or something that does not check with current practice. Formulas over the years may be expected to become obsolete, as the equipment itself, because of changes that take place in the manufacturing field.

No mathematical formula can be developed for judging absolutely when equipment should be replaced because there are too many variables, too many relatives, and too many intangibles that defy accurate measurement. Formulas in which net investment is divided by annual savings may be expected to show how soon the equipment will

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pay for itself, but it will do this only when correct amounts are
inserted in the formula. Formulas will break down when the variables
cannot be measured accurately and estimates have to be resorted to
in the calculations.

Then too, there is that tendency in the use of formulas to
delegate the responsibility for replacement studies to clerks, who
may have the ability to substitute in formulas, but who, on the other
hand, may not understand at all how to make proper replacement analyses.
Also, there is often that tendency to accept the numerical answer ob-
tained in the use of a formula as the final decision on whether or
not the replacement should be made. This is definitely misleading.
The results obtained from the use of formulas are only a part of
the answer. There is also that indispensable need of executive
judgement, which can only be obtained from practical experience.
All that even the best formula can do is to consider the tangible
factors. The reliability of the final decision on replacements is
dependent upon the wisdom and judgement of the investigator.

E. Intangible Factors.

Because there are so many variables, and so many intangible
factors to be considered, no final decision on replacements should
be made on the basis of cost comparisons alone. There are still
those practical considerations which have no immediate money value,
but which may nevertheless provide the ultimate weight of evidence
in favor of or against a given piece of equipment. This is the
primary reason why the final decision in replacement analyses
should always be made by an experienced executive.

What are some of these intangibles that may have so much weight on the replacement decision? Several are listed as follows:

(1) Improvements in accuracy or finish of the product.
(2) Ease of equipment operation and maintenance.
(3) Possibility of improved working conditions for employees. For example, would the equipment be difficult to keep clean and thereby contribute to the uncleanliness of the plant? (Machine operators will work more efficiently and accurately if they have clean surroundings).
(4) Better appearance of the plant (motor drives as against belt drives).
(5) Estimated relative flexibility to adapt to unforeseen conditions or types of product.
(6) The reputation of the supplier for building good equipment and standing back of it.
(7) Length of promised delivery.
(8) Guarantee of equipment supplier.

It is highly desirable that a guarantee of performance be obtained from the equipment supplier, because failure of such equipment to equal the estimated performance would soon offset any savings that had been forecasted and might cause a considerable loss. But a written guarantee is not always possible. Therefore, in such cases, it seems that the best guarantee would be to deal with reputable equipment builders whose reputations are at stake and who will see to it that the buyer gets proper performance from the equipment installed.
IV. PROPOSED METHOD OF REPLACEMENT ANALYSIS.

I have made a rather extensive and critical study of the several methods by which a replacement analysis may be performed. It is a result of this study and my thinking on the subject that I have selected and am proposing a method of replacement analysis which, in my opinion, is the most practical for actual use in modern industry. While the method is described in my own words, I have drawn liberally upon the ideas expressed in the publications of Professor Paul T. Norton, Jr., formerly of Virginia Polytechnic Institute, and Professor E.L. Grant of Stanford University.

A. Tabulation of Total Annual Costs (1).

All cost associated with each piece of equipment must be known or estimated before alternatives can be compared. Then a method of comparison must be agreed upon. There are several methods by which this comparison may be accomplished; however, it is believed that the best and most practical way would be on the basis of total annual costs. Instead of using a formula to determine how long it would take a piece of equipment to pay for itself or what rate of return might be expected on the investment, an orderly tabulation of total annual charges is prepared for each piece of equipment that is being compared. This total annual cost would be made up of two groups of

items, namely: (1) Fixed costs - those which remain practically fixed, which are proportional to the capital invested in the equipment, and which are unaffected by the volume of production; and (2) Operating costs - those which vary in some direct way with time or the volume of production.

That group designated as 'Fixed Costs' would consist of an investment charge based on a rate of return which would make the investment attractive when consideration is given to the risks that seem inherent in that particular investment, a depreciation charge which would repay the total investment in the equipment during the period within which it is expected to pay for itself, and an annual percentage allowance for taxes, insurance, and other similar charges. That group designated as 'Operating Costs' would include annual costs, which are either known or estimated, for direct labor, indirect labor, materials, repairs and maintenance, power, floor space, supplies and lubricants, and for any other operating expense that may be affected by the replacement. The actual determination of these various cost factors has been discussed in some detail in Section II-A of this thesis, which was entitled "Characterization and Determination".

If each alternative piece of equipment is charged with both fixed and operating expenses and the results for each totaled, the difference between total charges would be an indication of the relative advantage of one item of equipment over another. No attempt will have been made to determine how soon the equipment will pay for itself. This is not necessary however if this method is used. A decision is made as to the period during which the equipment
will be expected to pay for itself, the depreciation charge being based on this period. Nor is any attempt made to determine the rate of return that might be expected on the investment. Each investment in equipment, when this method is used, is charged with a return which would make the investment attractive when consideration is given to the risks involved. Since each piece of equipment is charged with a depreciation rate and a rate of return on investment that would make the replacement desirable, it is quite obvious that if the proposed equipment shows any further saving in total annual costs, the replacement would be justified from an economic standpoint.

It should be remembered that this method also considers only the tangible factors which are predictable and the value of which may be expressed in terms of dollars and cents. There is still that need for a careful consideration of all intangible and judgement factors before any final decision can be made. This comparison of annual costs should be looked upon as merely a part of an adequate replacement analysis.

This method of annual cost tabulation has several distinct and important advantages over the use of formulas. In the first place, even though it includes all the necessary cost factors that should be considered in a replacement analysis, it is much simpler than most of the formulas that have been developed. It is particularly adaptable for actual use in the ordinary manufacturing company and can be easily understood by those engineers and operating executives by whom the replacement analysis must be made.

It makes possible the comparison of any number of alternative
pieces of equipment at the same time, and in the same study, with no duplication of effort. Most formulas can be used to compare only two alternative pieces of equipment at a time, which obviously would make the solution of the problem rather involved and time-consuming where there are several proposed alternatives to be considered.

Furthermore, when total annual costs are tabulated and compared, it will give a better picture of the replacement problem. For example, a saving of $1,000 per year would not be nearly so important when it is the difference between total annual costs of $100,000 and $99,000 as when it is the difference between $10,000 and $9,000. A saving of $1,000 in the first case should not be given any great amount of weight since it is undoubtedly less than the probable error in calculations, which, in part, have been based on estimates. But in the second case, such a saving would be a material factor that might possibly lead to replacement of existing equipment. If, however, only this difference of $1,000 had been considered, as would be the case in most replacement formulas, both of the situations would have appeared exactly the same to an undiscriminating investigator.

B. Illustrated Examples.

In order that the reader may more clearly understand this proposed method of tabulating total annual costs against each piece of equipment, several selected examples of replacement analysis will be set forth using this particular method. Some of the data on first cost of equipment and on operating expenses that will be
used has been taken from publications or obtained through conference with plant executives. In most cases, however, it has been necessary to assume these figures, as well as the age and net realizable value of existing equipment, the depreciation rates, and the rates of return on invested capital. Some of the figures may vary from those incurred or expected in actual practice. It is merely the purpose of the author to show a practical technique of annual cost comparisons that might be followed by an investigator by substituting his own costs. No attempt is made to compute the various operating expenses. The reader may refer to Section II-A of this thesis for a rather detailed discussion of the methods of cost determination.

Let

\[ I = \text{In-place value of existing or proposed equipment.} \]
\[ D = \text{Annual percentage allowance for depreciation.} \]
\[ R = \text{Annual percentage allowance for return on investment.} \]
\[ T = \text{Annual percentage allowance for taxes, insurance, and similar charges.} \]
\[ L = \text{Annual total cost of direct labor.} \]
\[ B = \text{Annual total cost of indirect labor.} \]
\[ M = \text{Annual total cost of materials.} \]
\[ U = \text{Annual total cost of repairs and maintenance (upkeep).} \]
\[ P = \text{Annual total cost of power.} \]
\[ F = \text{Annual total cost of floor space.} \]
\[ S = \text{Annual total cost of supplies and lubricants.} \]
\[ C = \text{Annual total fixed costs.} \]

\[ C = I (D + R + T) \]

**Example 1.**

A company was considering the replacement of two 2-spindle
drill presses by one 4-spindle drill press. The existing presses were installed six years before and cost $8,000 each. The depreciation rate on these presses had been based on a 10 year life; therefore, the present book value of each is $3,200. However, the present realizable value of each is only $1,600. The 4-spindle drill press would cost $15,000 in-place and ready to operate. It will not be installed unless it will pay for itself in four years and at the same time earn a return of 12 per cent on the average investment. The 12 per cent return is that return which would make the investment attractive, risks being considered. Taxes and insurance will be figured at 3 per cent on the average investment. Operating costs have been computed, or estimated, for both the existing and the proposed presses.

The company figures depreciation by the straight line method. Since the investment in the presses will decrease each year as a result of depreciation charges, it is necessary to compute an average rate of return and an average percentage allowance for taxes and insurance for the four year period.

\[ R = 0.12 \times \frac{1}{4} \times \frac{4 + 1}{4} = 0.075 \]

\[ T = 0.03 \times \frac{1}{4} \times \frac{4 + 1}{4} = 0.019 \]
<table>
<thead>
<tr>
<th></th>
<th>Two 2-Spindle Presses</th>
<th>4-Spindle Press</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$3,200.00</td>
<td>$15,000.00</td>
</tr>
<tr>
<td>D</td>
<td>0.250</td>
<td>0.250</td>
</tr>
<tr>
<td>R</td>
<td>0.075</td>
<td>0.075</td>
</tr>
<tr>
<td>T</td>
<td>0.019</td>
<td>0.019</td>
</tr>
<tr>
<td>+ R + T</td>
<td>0.344</td>
<td>0.344</td>
</tr>
<tr>
<td>C</td>
<td>3,200 x 0.344 = 1,101</td>
<td>15,000 x 0.344 = 5,160</td>
</tr>
<tr>
<td>L</td>
<td>8,280</td>
<td>3,450</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>U</td>
<td>135</td>
<td>85</td>
</tr>
<tr>
<td>F</td>
<td>200</td>
<td>175</td>
</tr>
<tr>
<td>F</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S</td>
<td>95</td>
<td>60</td>
</tr>
</tbody>
</table>

Total: $9,811.00

From the above tabulation, it can be seen that the proposed 4-spindle drill press, if installed, would result in savings that would not only permit the press to pay for itself in four years and, at the same time, earn a desired rate of return of 12 per cent on the average investment during this period, but would show additional savings in the amount of $881.00 per year. From a cost standpoint, the replacement would be justified; however, there are still those intangible or judgement factors that must be considered before a final decision is made.
Example 2.

A company was considering the replacement of eight machines which were at the time seven years old. The cost of these machines had been 6,000 each, and they were being depreciated over a twelve year life. The book value of each machine was therefore $2,500, since the company figured its depreciation by the straight line method. The machines could be sold to a second-hand dealer for $2,000 each (the realizable value). Recent developments in the machine-builders' industry has made it possible for five new and improved machines of the same type to do the work of the existing eight machines. The cost of these new machines in-place and ready to operate would be $6,500 each. It is desired that they should pay for themselves in three years and at the same time earn a return of 15 per cent on the average investment. Taxes and insurance are figured at 2 per cent on the average investment. Operating costs have been computed, or estimated, for both the existing eight machines and for the five proposed machines. The remaining life of the existing machines will be figured on the basis of three years rather than on the five years remaining from the original twelve-year-life estimate because it would not seem reasonable to assume a longer life for the existing machines than that during which the new machines are expected to pay for themselves. The company expects to use for other productive purposes any floor space than can be saved by the replacement.

\[ R = 0.15 \times \frac{1}{2} \times \frac{2 + 1}{3} = 0.10 \]

\[ T = 0.02 \times \frac{1}{2} \times \frac{2 + 1}{3} = 0.013 \]
<table>
<thead>
<tr>
<th></th>
<th>Existing Machines</th>
<th>Proposed Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I  $16,000.00</td>
<td>I  $32,500.00</td>
</tr>
<tr>
<td></td>
<td>D  0.333</td>
<td>D  0.333</td>
</tr>
<tr>
<td></td>
<td>R  0.100</td>
<td>R  0.100</td>
</tr>
<tr>
<td></td>
<td>T  0.013</td>
<td>T  0.013</td>
</tr>
<tr>
<td></td>
<td>D + R + T  0.446</td>
<td>D + R + T  0.446</td>
</tr>
<tr>
<td></td>
<td>C  $16,000 x 0.446 = 7,136</td>
<td>C  $32,500 x 0.446 = 14,495</td>
</tr>
<tr>
<td></td>
<td>L  22,000</td>
<td>L  15,000</td>
</tr>
<tr>
<td></td>
<td>B  -</td>
<td>B  -</td>
</tr>
<tr>
<td></td>
<td>M  -</td>
<td>M  -</td>
</tr>
<tr>
<td></td>
<td>U  710</td>
<td>U  320</td>
</tr>
<tr>
<td></td>
<td>P  1,450</td>
<td>P  900</td>
</tr>
<tr>
<td></td>
<td>F  900</td>
<td>F  500</td>
</tr>
<tr>
<td></td>
<td>S  510</td>
<td>S  220</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>$ 32,706.00</td>
<td>$ 31,435.00</td>
</tr>
</tbody>
</table>

From the above tabulation, it can be seen that the five modern machines, if installed, would result in savings that would not only pay back the investment in three years and earn a desired rate of return of 15 per cent on the average investment during this three year period, but would result in an additional saving of $1,271 per year. From a cost standpoint the replacement would be justified.
CONCLUSIONS AND RECOMMENDATIONS.

In the light of the preceding discussion on the economic selection and replacement of manufacturing equipment, I have concluded that American industrial executives face the necessity of examining the present status of their capital accounts and equipment policies and of developing future equipment policies embracing accurate, sound, and adequate principles. It is therefore in the interest of more efficient and progressive equipment policies that a number of recommendations are set forth. I recommend:

(1) That more attention be paid to definite long-time planning of equipment policies.

(2) That adequate provisions be provided in depreciation allowances to account for impending obsolescence.

(3) That any practice of linking replacements with the age of equipment be discontinued.

(4) That industrial executives become aware of the true nature of the depreciation reserve account.

(5) That the financing of equipment replacements be achieved not through a regular replacement fund set aside out of profits but through a company surplus which is controlled so that the necessary funds will be available when needed.

(6) That, in many cases, it would be a good practice to make replacements each year at a rate equal to the amount of depreciation that actually occurred during that year.

(7) That the responsibility for replacement analyses lie with ex-
rienced executives and not with clerks.

(8) That industrial executives make adequate provisions for keeping themselves abreast of improvements and developments that are continually being made in equipment.

(9) That, if such arrangements can be made, the proposed equipment be put into the factory on a trial basis when the equipment is entirely new and different.

(10) That, before obsolete equipment is sold to a second-hand dealer, consideration be given to the probability of it coming into the hands of a competitor at a low cost and thereby increasing competition.

(11) That adequate provisions be made in accounting systems for developing economic information that will enable the engineer and operating executive to know the exact conditions that exist with present equipment.

(12) That equipment policies be based on accurate and adequate cost accounting systems and not merely follow a practice of buying and scrapping equipment empirically.

(13) That a plant ledger record, either in the form of a book card index or a loose-leaf record, be set up, which will provide accurate cost information on equipment.

(14) That, in the actual replacement analysis, the basis of fixed charges on the proposed equipment be its total cost in-place and ready to operate.

(15) That, in the actual replacement analysis, the basis of fixed charges on the existing equipment be its net realizable value and not its original cost or book value.

(16) That the depreciation rate used in the replacement analysis
ear no relationship to the depreciation rate used in the accounting
records, or that which will be used if the proposed equipment is actu-
ally installed.

(17) That, in the actual replacement analysis, the depreciation
rate be based upon the period of time in which the equipment is expected
to pay for itself.

(18) That any period of time established during which the equip-
ment must pay for itself have a reasonable basis, or, in other words,
that caution be taken to assure that time limits are not too severe.

(19) That equipment be required to pay for itself in the early
years of its life, or, in other words, that liquidation value be ap-
proached as rapidly as possible.

(20) That, in the replacement analysis, the salvage value of pro-
posed equipment be arbitrarily assumed as zero.

(21) That the straight line method of depreciation be used to
compute the depreciation charge that is used in the replacement analysis.

(22) That, in the replacement analysis, the capital investment
required for each alternative piece of equipment be charged with that
rate of return which would make the investment attractive when consid-
eration is given to the risks that seem inherent in that particular
investment.

(23) That the practice of arbitrarily assuming that indirect labor
cost will increase or decrease in the same proportion as the increase
or decrease in direct labor that is expected as a result of equipment
replacements be discontinued.

(24) That, in the replacement analysis, overhead be broken down
into its elements and each analyzed separately.

(25) That provisions be made in accounting records for accumulating repair and maintenance expense by machine, or each piece of equipment.

(26) That a proposed machine not be credited with any potential saving in floor space unless the space that is released is expected to be used for some other productive purpose.

(27) That a proposed machine not be credited with any extra potential capacity unless this extra capacity is actually to be used.

(28) That management not be finically scrupulous in their replacement analysis and calculations nor in their search for minor and uncertain differences in economic performances between alternative equipment.

(29) That cost comparisons in the replacement analysis be based on equal expected services, the same service in alternative ways.

(30) That cost and revenues which are unaffected by the choice of equipment be omitted from the replacement analysis.

(31) That equipment policies be flexible enough to be adjusted to conditions as they change.

(32) That no definite period be established in which the equipment must pay for itself, but that each purchase of equipment be made strictly on the merits of the case.

(33) That the unamortized value of obsolete equipment not be charged against the proposed new equipment, but that it be charged off to Profit and Loss, to Surplus, or to a Replacement Reserve.

(34) That extreme caution be taken in the use of formulas for making replacement analyses.
(35) That no final decision on replacements be made on the basis of cost comparisons alone, but that all the intangible and judgement factors be brought to bear on the problem also before any decision is made.

In general, I conclude that an orderly tabulation of individual and total annual charges, such as discussed in this thesis, is the best and most practical method that could be used in making replacement studies.
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Equipment Buying Formula. 

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COMPANIES VISITED

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Allis-Chalmers Manufacturing Company
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Ben-Burk, Inc.
1010 Massachusetts Avenue, Boston, Massachusetts

Blanchard Machine Company
64 State Street, Cambridge, Massachusetts

Boston Woven Hose & Rubber Company
29 Hampshire Street, Cambridge, Massachusetts

National Ice Cream Company
168 London Street, Boston, Massachusetts

Pneumatic Scale Corporation, Ltd.
65 Newport Avenue, Quincy, Massachusetts

Walter Baker Division of General Foods Corporation
1197 Washington Street, Boston, Massachusetts

Welch Candy Company
810 Main Street, Cambridge, Massachusetts

Wigglesworth Machine Tool Company
199 Bent Street, Cambridge, Massachusetts