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ECONOMIC DATA COMPUTER

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This invention relates to the computer art and has particular relation to computers of the type with which economic data may be readily calculated. While this invention arose out of the problems of computing economic data and this invention in its specific aspects concerns itself with these problems, the concepts on which this invention in its broader aspects is based have applicability to computers of other types. To the extent that this invention is applicable to the latter such applications are within the scope of this invention.

Economic data is characterized by the fact that it is governed by a large number of variable factors and the equations from which such data is derivable are of a quasi empirical character including parameters in various forms corresponding to all or at least the most important of these factors. In addition, economic data calculations such as the calculations of return-on-investments involve equations similar to those used in the calculation of interest data. Such equations are not readily solved in a simple manner nor are they readily transformable into simpler equations.

It is then broadly an object of this invention to provide a computer with which a relatively unskilled operator can derive economic data from the equations defining the desired data.

To facilitate the understanding of this invention it is believed desirable at the outset to explain the meaning of some of the unusual terms which will be used in this application and to review several equations of different types with which this invention concerns itself. An equation usually expresses a so-called dependent variable or dependent parameter as a function of one or more independent variables or independent parameters. It is contemplated that in applying such an equation the independent variables will be changed over certain ranges and thus determine the magnitude of the dependent variables. In general terms an equation of the type just mentioned may be written:

$$z=f(x,y)$$

In this equation, z is the dependent variable and x and y are the independent variables. Sometimes the form of f is such that the equation may be transformed so that either x or y may become a dependent variable and z an independent variable. Such a transformed equation would be

$$x=f_1(y,z)$$

An equation dealing with economic data may usually be expressed as the algebraic sum of a plurality of terms equated to zero. For example, the above equation may be written

$$z-f(x,y)=0$$

The parts z and $f(x,y)$ are called the terms of this equation.

Each term of an equation may have any general form. Specifically, a term may consist of a product of several variables for example, $f(x,y)$ would be the product axy. A term may also consist of the algebraic sum of a plurality of other terms multiplied by a third parameter or one of the terms. Thus a term in the above equation could be the product $a(x-y)$.

The equations defining the economic data with which this invention concerns itself include the functions of the different types and the equation forms of the different

types just mentioned, and it is a specific object of this invention to provide a computer which shall include facilities for readily simulating the functions of the different types discussed above and for solving equations including such functions.

Among the equations with which this invention concerns itself is the classical equation for computing economical manufacturing lot size (see Product Engineering Mid October, 1957, page A–2 "Economic Lot Size for Manufacture," Edward C. Varnum). This equation is used in determining the most propitious quantity of items to be manufactured in replenishing stock. The quantity of items is referred to as lot size. The classical economic lot-size equation expresses the lot size L as

$$L=\sqrt{\frac{24ms}{FC}} \tag{1}$$

In this equation

m=the number of units used per month (this will usually be set month by month).
s=the cost of setting up the machine for making items.
F=carrying charge on the items in percent.
C=the unit cost per item in dollars.

In a modern organization such as one of the automotive companies or one of the large electrical companies, thousands of items are maintained in stock. Since the lack of even a single one of these many items can stop a production line at large economic cost or send a customer to a competitor, it is necessary that the utmost care be given to maintaining the stock. But it is also essential that the replenishment of the stock be carried out economically at a minimum cost. The most economic lot size for each item can be calculated on the basis of Equation 1 just discussed but where a large number of items are involved the labor of carrying out the calculations long hand, even with handbooks, and the possibility of costly errors constitute a serious inconvenience.

It is then an object of this invention to provide a computer of relatively simple structure with which clerical personnel could readily and accurately calculate economic lot size on the basis of the above described classical economic lot-size equation or a like equation.

In arriving at the aspect of this invention concerning economic lot-size Equation 1, it was realized that the calculations must be relatively precise and that the range in the magnitude of the various factors of this equation which would be encountered in practice would vary widely for each factor and would differ radically for the different factors. Thus, the factor m could be as high as 100,000 or 1,000,000, and could be as low as one or two. The factor s could be several dollars or several hundred dollars. The factor F could be 1% or as high as 30 or 50%, the factor C could vary from a few cents to one thousand dollars. This invention to the extent that it concerns the calculations based on Equation 1 arises from the realization that in determining L from Equation 1 the various factors should be set on a logarithmic rather than a linear scale. Thus Equation 1 can be written:

$$2\log L=\log 24+\log m+\log s-\log F-\log C \tag{2}$$

or

$$2\log L-\log 24-\log m-\log s+\log F+\log C=0 \tag{3}$$

As last expressed, the classical economic lot-size Equation 3 consists of the sum of a plurality of terms (that is the log terms) equated to zero.

In accordance with this invention apparatus is provided for determining log L from which the lot size may be readily calculated. This apparatus includes a meter and a plurality of variable electrical components, each component corresponding to a parameter or variable of the above equation. The components are connected in series and a potential having a magnitude equal to the corresponding parameter is impressed across each component and a voltmeter is connected across the components to measure their net voltage. So that the settings of the variable resistors may be comparable, the units adopted for the potential across all the resistors must be the same. A convenient unit is the volt.

In the use of the apparatus, the magnitude for the various terms log 24, log *m*, log *s*, log F and log C are set on the corresponding components and the component corresponding to log L is varied until the meter reads zero. The setting of the latter component then determines the magnitude of 2 log L.

In accordance with one specific aspect of this invention, the components are a plurality of variable resistors each connected across the secondary winding of a transformer. The number of turns of each secondary winding is so related to the number of turns of its associated primary winding that the potential across each secondary winding corresponds to the range of variation of the corresponding parameter.

In accordance with another specific aspect of this invention, a variable transformer for example a Variac transformer is provided for each of the terms. Each variable transformer is preferably an autotransformer and its seconday supplies a transformer from the secondary of which potentials corresponding to the parameter represented by the variable transformer is derivable. The latter transformers are so related that each supplies a secondary potential, which expressed in volt unit, is capable of covering the range of variation of the corresponding parameter.

The classical economic lot-size equation is an equation in a few selected parameters. The practical conditions to which it is applied in many cases involve a far larger number of parameters, some of them highly complex, which are related to each other in complex ways.

Higher accuracy than that available from Equation 1, may be obtained by introducing some of the most important of these additional parameters. Specifically the product FC which, in effect, is the carrying cost of the items, can be broken down into its more important component costs. Where the apparatus in accordance with this invention is to have this additional accuracy the product FC is replaced by a factor K. This factor K has been found by Dr. Paul T. Norton, Jr. to be given by the following equation:

$$K=\frac{(B+I)C+ZA(1-R)}{2} \qquad (4)$$

in which:

B=Taxes, insurance and other like charges in percent per year on each item in the inventory.

I=Desired return on the capital invested on each item in stock in percent per year.

C=As before is the unit cost per item in dollars.

Z=A factor which is governed by the storage space for the item. Where the storage space is to be reserved, $Z=2$. Where any storage space avalibale may be used, $Z=1$.

A=The cost of floor space for one item for one year in dollars.

$$R=\frac{M}{P}$$

where

M=the units used per month or per any unit of time which may be changed from month to month, and

P=the number of items made per month or per the same unit of time with the apparatus set up. (P must be changed as the facilities for production changes.) (See Economic Lot Sizes In Manufacturing, Paul T. Norton, Jr., Professor of Industrial Engineering, Virginia Polytechnic Institute, Extension Bulletin No. 31.)

The ratio R will be supplied to the personnel making the calculations periodically as it may change.

For convenience two new equations may now be written. One of these equations is

$$Q_e=\sqrt{\frac{12MS}{K}} \qquad (5)$$

Q_e=economic lot size.

S=total preparation cost per lot. This includes the cost of preparing manufacturing orders, the cost of setting up the machine, and any other costs independent of the number of items in the lot.

M=times used per month.

K is defined by Equation 4.

The equation for K includes the product $(B+I)C$, and $ZA(1-R)$, that is the product of a sum of terms $(B+I)$ or $(1-R)$ and a parameter C or ZA and is a specific object of this invention to provide a variable electrical network for setting a magnitude corresponding to this product. The equation for Q_e may be written

$$2\log Q_e-\log 12-\log S-\log M+\log K=0 \qquad (6)$$

The determination of Q_e thus involves the solving of log Equation 5 which, in turn, involves solving the linear Equation 4 for K.

The calculation of lot size from Equations 4 and 5 even for one item is a tedious and time-consuming task. Where hundreds or thousands of items may be involved this task becomes impossible and it is a specific object of this invention to provide apparatus with which calculations such as that involving Equations 4 and 5 may be readily made.

In accordance with this invention, a computer is provided which includes a plurality of variable electrical components, each component corresponding to a term of the log Equation 6 and each component having a range of variation corresponding to the parameter which it represents; in addition, a second plurality of variable components are provided, each corresponding to a term of the equation defining K. In addition, the apparatus includes a meter and a selector switch having two positions. In one position of the selector switch, the impedances representing the log components are connected in a network with the meter; in the other position, the impedances representing the terms of the equation for K are connected in a network with the meter. Each of the variable components has a scale. The scale for the components representing the log terms is logarithmic. The other scales are linear. A potential which in volts is equal to the parameter represented by the component is impressed across each component.

In using the apparatus, the selector switch is first moved to the position in which the meter is connected to the linear components. The potential across each linear component is then set so that the number of volts is equal to the magnitudes B, I, C, Z, A and R, respectively, and the variable components corresponding to K is varied until the meter reads zero. The switch is then moved to the other position and the potentials across the variable components representing the log terms are now set to correspond to log K, log M and log S and the potential across the component representing log Q_e is varied until the meter reads zero. Thus the magnitude of log Q_e is derived.

In accordance with a specific aspect of this invention, a variable electrical network is provided for apparatus of the above described type for setting a magnitude corresponding to a product such as $(B+I)C$ or $ZA(1-R)$ consisting of the sum of a plurality of terms multiplied by a parameter (or another sum). This network includes a variable transformer on which the single factor C or ZA of the product may be set. The variable transformer supplies a plurality of variable resistors on each of which the terms of the other factor of the product may be set. Where each factor includes a sum of terms a plurality of variable transformers in series may supply a plurality of variable resistors.

A still further feature of the invention involves the calculations of return-on-added-investment. In calculating return-on-added-investment, the problem is usually to compare the return on an investment of one type with the return-on-investment of another type. Mathematically, this problem may be defined by the equation:

$$P1+(I1-L1)CR1+L1i=P2+(I2-L2)CR2+L2i \quad (7)$$

This equation presents the two alternatives herein called alternative I and alternative II to which the numbers 1 and 2 after the letters correspond. In this equation:

$P1$=the annual cost of operating equipment of alternative I to produce a product.
$P2$=the annual cost for alternative II.
$I1$=initial investment in the equipment of alternative I.
$I2$=initial investment for alternative II.
$L1$=the salvage value of the equipment under alternative I.
$L2$=the salvage value of the equipment under alternative II.
i=rate of return-on-investment in percent.
$CR1$=Capital recovery factor for alternative I. This capital recovery factor is a function of i and the number of units of time, n, anticipated for the equipment.
$CR2$=Capital recovery factor for alternative II.

The time unit is equal to the period during which the capital investment is compounded. The unit may be a year or six months or even less. If the compounding takes place annually n is in years. If the compounding takes place at shorter intervals than years, n would be higher than for years. Thus, if the compounding takes place at intervals of six months and the life of the equipment is 10 years, n would be 20 rather than 10. In the following discussion it will be assumed that n is in years.

It is of interest to derive the equation for CR1 or CR2 so that its significance will be understood. CR1 and CR2 are, in fact, equal to a factor such that I1CR1 (or I2CR2) is the annual payment which would pay for an item of equipment having an initial cost I1 or I2 and having a life of n years, assuming that the return-on-added-investment is i.

It is assumed that the investment I in the equipment is made at the beginning of a year and that the amount CRI is realized or paid at the end of each year of the life of the equipment. Let D equal the amount realized or paid at the end of each year. The problem resolves itself into finding D, assuming that it is equal for all years and that at the end of n years the equipment has paid for itself. For the first year the gain in I is Ii and the value of the initial investment is $I(1+i)$. At the end of the first year D is subtracted from this so that the investment becomes $I(1+i)-D$. At the end of the second year, the corresponding value is

$$I(1+i)^2-D(1+i)$$

At the end of the third year, it is

$$I(1+i)^3-D(1+i)^2-D(1+i)$$

At the end of the nth year, then the quantity is

$$I(1+i)^n-D[(1+i)^{n-1}+(1+i)^n \ldots 1]$$

and

$$I(1+i)^n-D[(1+i)^{n-1}+(1+i)^n \ldots 1]=0$$

Applying the equation for the sum of a geometric progression this becomes

$$I(1+i)^n-D\frac{(1+i)^n-1}{i}=0$$

or

$$D=I\frac{i(1+i)^n}{(1+i)^n-1}$$

Then

$$CR=\frac{i(1+i)^n}{(1+i)^n-1} \quad (8)$$

CR1 and CR2 in the above Equation 7 are then an intricate function of i and n and it is not readily feasible to transform the Equation 7 so that it is expressed as a function of i alone and n alone.

It is then a further object of this invention to provide apparatus for readily determining the magnitude i or any of the other parameters of an equation similar to the above Equation 7 in which one of the parameters appears as a simple function and also as an intricate function so that the equation may not be readily transformed into an equation in the one parameter alone.

This aspect of the invention arises from the realization that sound approximation may be made by initially disregarding certain of the terms of the equation which include either the parameter alone or the intricate function of the parameter. Consideration of the above Equation 7 reveals that the parameters L1 and L2 the salvage value are usually substantially smaller than I1 and I2. In accordance with this invention then apparatus is provided which permits an initial approximate determination of the rate-of-return-on-added-investment i by initially eliminating the salvage value terms, that is L1i and L2i, from the equation. Equation 7 then becomes

$$P1+(I1-L1)CR1=P2+(I2-L2)CR2 \quad (9)$$

In this equation 9, CR1 and CR2 are different only because the number of years n are different. But it may be assumed that these are alike to a first approximation so that with I1, L1, I2, L2, P1, P2 known, the magnitude of CR may be derived from the Equation 9 which may be expressed as a known function of i and n. Since CR is expressed as a known function of i and n it may be calculated directly for a reasonable succession of values of i and n or it may be found in tables for different values of i and n. Thus the approximate value of CR, i and n may be derived from Equation 9 for any values of parameters or conversely knowing i and n, CR may be known any any of the parameters P1, P2, L1, L2, I1, I2 may be determined if the others are known. Starting with these approximate values more accurate values may be determined.

In accordance with this invention, apparatus is provided which includes a plurality of variable electrical components each corresponding to a term of the above Equation 7. The components corresponding to P1, P2, I1, I2, L1, L2 are preferably variable resistors. The components which correspond to i and CR1 and CR2 are variable transformers properly connected to the resistors. The apparatus also includes a selector switch and a meter. The meter is connected in series with the components. The switch is connected to the variable transformers corresponding to CR1 and CR2 and has two positions. In one of the positions of the switch the components corresponding to I1, L1, I2, L2 are connected to one of the variable transformers corresponding to CR1 or CR2 so that, in effect, CR1 and CR2 are equal, that is, are set for equal n. In the other position of the switch, the variable transformer corresponding to CR1 is connected to the components corresponding to I1 and L1 and the transformer corresponding to CR2 to those corresponding to I2 and L2.

In the practice of this aspect of the invention, the apparatus is initially set in the first position, the transformer corresponding to i is set to zero volts, and an approximate magnitude of CR, assuming equal n, is determined. The apparatus is then connected so as to represent all of the terms and factors of Equation 7 and starting with the magnitude of i which was derived by the first approximation a more precise magnitude of i is derived.

In dealing with the factor CR in Equation 7 it is necessary that a variable electrical component, specifically a variable transformer, which can readily be set by an operator over a wide range of return-on-added-investment and for different years is provided and it is a specific object of this invention to provide such a component.

In accordance with this aspect of applicant's invention a variable electrical component having separate scales for years and return-on-added-investment is provided. These scales are so correlated that for each setting of the component the value of i for a series of values of n satisfying Equation 8 may be determined.

The novel features considered characteristic of this invention are disclosed generally above. The invention itself both as to its organization and as to its method of operation, together with additional objects and advantages thereof, will be understood from the following description of specific embodiments when taken in connection with the accompanying drawings, in which:

FIGURE 1 is a circuit diagram of an embodiment of this invention for calculating economic lot size;

FIG. 2 is a diagrammatic view showing the panel of the apparatus shown in FIG. 1;

FIG. 3 is a circuit diagram of a modification of this invention shown in FIGS. 1 and 2;

FIG. 4 is a circuit diagram of a further modification of this invention for calculating lot size more accurately and conveniently than with the apparatus shown in FIGS. 1, 2 and 3;

FIG. 5 is a circuit diagram of an embodiment of this invention for calculating rate-of-return-on-added-investment;

FIG. 6 is a diagrammatic view of the panel for the apparatus shown in FIG. 5;

FIG. 7 is a view in front elevation of a dial used in the apparatus shown in FIGS. 5 and 6; and

FIG. 8 is a view in front elevation of a modification of the dial shown in FIG. 7.

The computer shown in FIGS. 1 and 2 is supplied from a pair of conductors SL1 and SL2 which may be connected to the buses of a single-phase alternating-current commercial supply. The conductors SL1 and SL2 supply the primary 1TP of a transformer 1T which has a plurality of secondaries 1TS1, 1TS2, 1TS3, 1TS4, 1TS5 and 1TS6 corresponding in number to the number of terms in the log Equation 3 for L. Secondary 1TS1 corresponds to 2 log L in the equation, secondary 1TS2 to log 24, secondary 1TS3 to log m, secondary 1TS4 to log s, secondary 1TS5 to log F, secondary 1TS6 to log C. Across each of the secondaries 1TS1, 1TS3, 1TS4 and 1TS6, a variable resistor 1R, 2R, 3R and 6R are connected. Across secondary 1TS5, a variable resistor 5R having in series a fixed resistor 4R is connected. The number of turns of each of the secondaries of 1TS1 through 1TS6 is so related to the number of turns of primary 1TP that the potential across each secondary expressed in volts corresponds to the range of variation of the log of the parameter to which the secondary corresponds. Each of the resistances 1R, 2R, 3R, 4R, 5R and 6R also has a magnitude corresponding to the range of the log of the parameter to which it corresponds.

The apparatus also includes a meter 1M particularly suitable for null setting. A sensitivity resistor 7R is associated with this meter. For sensitive operations, the resistor 7R may be short-circuited by a push button PB. The resistors 1R through 6R and the secondary 1TS2 are connected in a network in series with the meter 1M and the resistor 7R. Each of the resistance components is poled in the network correspondingly to the sign of the term in the log equation to which it corresponds. The polarity at any instant is shown in FIG. 1. Thus assuming that the polarity across resistor 1R is at this instant positive at the left-hand terminal and negative at the right-hand terminal, the secondary 1TS2 will be at this instant negative at the left-hand terminal and positive at the right-hand terminal, the resistor 2R negative at the left-hand terminal and positive at the right-hand terminal, the resistor 3R negative at the left-hand terminal, and positive at the right-hand terminal and resistors 4R—5R positive at the left-hand terminal and negative at the right-hand terminal and the resistor 6R positive at the left-hand terminal and negative at the right. It is seen that each of the above described polarities corresponds to the polarity of the log terms in the equation.

The following Table I is a concise presentation of the important features of apparatus as disclosed in FIGS. 1 and 2 and of the potentials of the secondaries of typical apparatus which has been constructed and found to operate satisfactorily.

Table I

Term	Secondary	Potential, v.	Parameter	Range of Variation
2 Log L	1TS1	230	Economic lot size.	0 to 1,000,000.
Log 24	1TS2	26.45		
Log m	1TS3	57.5	Items used per month.	0 to 100,000.
Log s	1TS4	95.8	Machine set-up cost.	0 to $1,000.
Log F	1TS5	10	Carrying charge.	5 to 30%.
Log C	1TS6	57.5	Unit cost per item.	0 to $1,000.

The apparatus shown in FIG. 1 is mounted in a cabinet which may be generally rectangular and may have a panel as shown in FIG. 2. The knobs KN1, KN2, KN3, KN5 and KN6 of the variable resistors 1R, 2R, 3R, 5R and 6R project through the panel. Each of the knobs KN1 through KN6 is provided with a pointer which is movable over a scale SC1, SC2, SC3, SC5 and SC6 corresponding to the argument of the term set by the associated resistor. The scales are of logarithmic form and each is calibrated in terms of the argument; that is scales SC1 and SC2 in items, scales SC3 and SC6 in dollars and scale SC5 in percent. The panel is provided with a window W through which the pointer P0 of the meter 1M may be seen. The push button PB and the handle of an on-off switch SW also project to the top. In addition, there is a pilot lamp LA which shows that the apparatus is energized and a receptacle RE for connecting a power cable.

In the use of the apparatus, the conductors SL1 and SL2 are energized and the knobs KN2, KN3, KN5 and KN6 are set to correspond respectively to the number of items used per month, the machine setup cost, the carrying charge factor, and the unit cost. The knob KN1 is then moved until the meter 1M reads zero. Thereafter, the sensitivity push button PB is closed and further adjustment of resistor 1R with KN1 takes place until the meter again reads zero. The economic lot size can then be read from the scale SC1 of resistor 1R.

In the apparatus shown in FIG. 3, the settings are produced on variable transformers rather than variable resistors. This apparatus includes the variable transformers 7T, 8T, 9T, 10T and 11T corresponding to the terms of the equation, 2 log L, log m, log s, log F, log C, respectively. The transformers 7T and 8T through 11T are of the autotransformer type (and may be Variac transformers). The secondary potential is derivable between one of the terminals of each transformer and the adjustable arm. The secondary of each of the variable transformers supplies the primary of an associated transformer 31T, 33T, 34T, 35T and 36T, respectively. The secondaries 31S, 33S, 34S, 35S and 36S of the latter transformers and secondary 32S of a transformer 32 corresponding to the term log 24 are connected in a net-