Quaestiones Informaticae

Vol. 2 No. 3 September, 1983

Quaestiones Informaticae

An official publication of the Computer Society of South Africa and of the South African Institute of Computer Scientists

'n Amptelike tydskrif van die Rekenaarvereniging van Suid-Afrika en van die Suid-Afrikaanse Instituut van Rekenaarwetenskaplikes

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Quaestiones Informaticae is prepared for publication by Thomson Publications South Africa (Pty) Ltd for the Computer Society of South Africa and the South African Institute of Computer Scientists.

Evaluating the Performance of Computer-Based Information Systems using a Restricted Linear Regression Model

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Abstract

Performance evaluation techniques can contribute substantially to the successful management of the information services function in an organization. Unfortunately the design and implementation of computer-based information systems have for a long time been (and in some organizations are still being) accepted as being primarily technical activities. Some of the most serious constraints on the design, installation and use of computer-based systems are not technical in nature and from the literature it has emerged that many computer-based systems have failed, not necessarily as a result of poor technical quality, but because certain other important aspects which determine the success or the failure of a computer-based system have been ignored. The objectives of this study may be summed up in four main points, viz.:

(i) to investigate the use of computer-based information systems and their success as perceived by the user;

(ii) to determine which factors make the largest contribution to the success of a computerized system;

(iii) to determine, by means of optimizing methods, which factors are the most important to change in order to obtain optimal improvement in the performance of the information systems; and

(iv) to formulate a model which would enable the management of an organization to apply funds in such a way that the computerized systems may provide optimum performance.

1. Introduction

Various researchers most notably perhaps Lucas [10], [11], [13]) have investigated the use and application of computer-based information systems. Some others, who have also made contributions to this and related fields, include Enid Mumford [15], E. Burton Swanson [18], Russel R. Ackoff [1], R.D. Mason and I. Mitroff [14], M.S. Scott Morton [17], John T. Garrity [8] and J. Huysmans [9].

The main reason for this study was the fact that most computer-based information systems today fail not as a result of poor technical quality, but because certain other important factors are not considered [13]. If those factors are known, how can management use this knowledge to improve the information systems performance? How are they going to spend the available funds to improve the quality of the systems? Is there an optimal way to apply the funds to improve the success of the systems "optimally"? This study was undertaken to provide some answers to these questions.

In section 2 the field study is discussed. Included in this section are the various statistical methods used and the linear regression function obtained from the processed data. In section 3 the restricted linear regression model method used in the further analysis is described. Section 4 consists of a description of the cost models which were developed and in the fifth and last section a few conclusions are made.

2. The Field Study

From the literature it is clear that certain factors are of utmost importance in their contribution to the success of computer-based systems. These factors are used in a descriptive model (figure 1). In order to be able to determine the relationships as hypothesized in the model, data from users of computerized systems in a very large organization were collected. In this organization there are about 140 computerized systems used by 1 200 clerical staff and 114 managers.

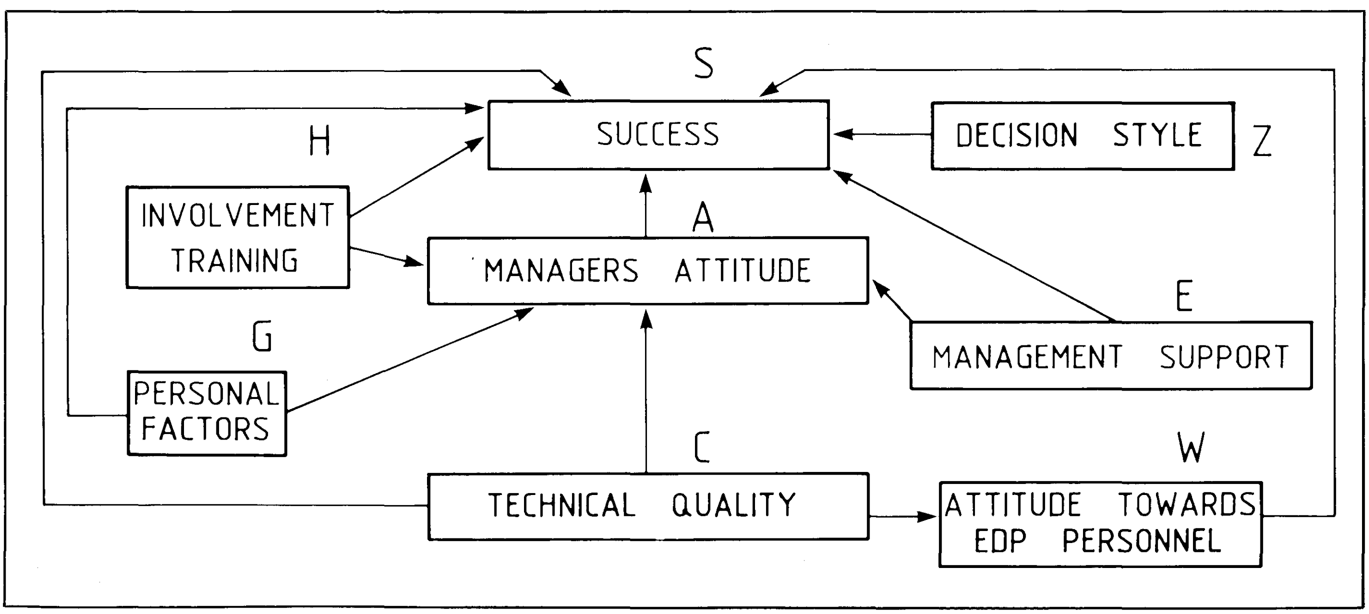


FIGURE 1: Hypothetical research model.

Questionnaires were designed for the managers and the full population of managers was involved in the investigation. Most of the questions in the questionnaire could be answered on a 7-point scale ([3], p. 282). With the aid of statistical computer programs [5], correlation and regression methods were used to investigate the existence of linear relationships between certain variables in the model and the success of computerized systems. How is success defined operationally? In past studies success has been measured by a number of indicators including actual use, intended use, attitudes, etc.

A cost/benefit study is one of the best ways to measure success. The benefits obtained from a computer-based system should exceed the costs of developing and running the system. Unfortunately, assessing the benefits of systems efforts has been difficult, particularly for systems supporting sophisticated decision making beyond the routine processing of transactions. What are the benefits of strategic planning to the firm? How can the results of strategic planning be evaluated against performance with no planning at all?

Because of the extreme difficulty of measuring success through cost/benefit studies, some other indicator of success is needed. The most appealing indicator from a measurement standpoint is system use. However there are instances where a high level of system use is not a sign of success of the system. When the use of a computer-based system is involuntary, this criterion can not be used. The third criterion which was used in this study, is user satisfaction with the system. Use and satisfaction are relative, that is, they are measured in general on a continuous scale as opposed to a binary scale. Less and more satisfaction are then defined operationally by where individuals fall on the continuous scale.

The data collected from the managers were used to obtain a linear regression model in terms of which success could be explained. To be able to do this, the following method was used: By using factor analysis [6], the variables used in the questionnaire to determine the success of the computerized systems were combined to form a single factor. Success could now be predicted by means of a linear relationship of a number of variables. With the aid of a stepwise linear regression computer program ([6], p.455), the number of independent variables in terms of which success could be explained was reduced to 18 variables (the number at the outset had been 39). These variables explained 72% of the variation of the success variable. However, because there was a need for as simple a model as possible for the rest of the study, a multiple linear regression program ([6], p.459) was used to select the "best" subset of independent variables in terms of which success could be explained by the following 12 variables:

- A — the attitude of management towards computerization
- E — management support
- C_1 — degree of detail in output reports (too much)
- C_2 — degree of detail in output reports (too little)
- C_3 — accuracy of information
- H — involvement of management
- G — term of service of managers
- T — availability of resources
- W_1 — technical quality of computer personnel
- W_2 — quality of the manager's managerial skills
- W_3 — training provided for users
- W_4 — extent to which users were involved in computerizing projects

The linear regression model which evolved is given below:

$$S = -3{,}74 - {,}08A, + {,}14C_1 - {,}14C_2 + {,}23C_3 + {,}05H + {,}08T - {,}07G + {,}34W_1 + {,}11W_2 + {,}10W_3 - {,}26W_4 \qquad (1)$$

This model can be used for prediction purposes and the influence of a specific independent variable on the dependent variable is now of interest. Should there be no interdependence between the decision variables, one could merely note the regression coefficient of the specific variable. In such a situation it would be theoretically possible to determine the maximum of the dependent variable by making those values of decision variables which have positive regression coefficients as high as possible, and those which have negative coefficients, as low as possible.

The problem with this approach is the fact that the combination of levels of the variables could be of such a nature that it can not be physically implemented. For example in this project no data points were observed where the variable T (availability of resources) was at a low level while the variable W_1 (technical quality of computer personnel) was at a high level and vice versa. It should thus be accepted that one can only suggest levels of variables which would fall within the area of experience, that is, combinations of levels of variables that were observed.

3. The Restricted Linear Regression Model Method

The field of experience, that is, the space covered by the available data points, is of significance here. For this reason the convex hull of available data points was considered. In this project data were collected from 114 managers so that 114 data points were available. To determine the convex hull all convex combinations of data points observed must be considered. For simplicity we let X_j denote the appropriate variable in (1) above and $X_{i,j}$ the i-th observation on variable X_j. Should we consider the points

$$V_i\ (X_{i1}, \ldots, X_{ik}) \text{ for } i = 1, 2, \ldots, 114 \text{ and } k = 12 \qquad (2)$$

the convex hull could be represented by the following set:

$$C = \{z = (X_1, X_2, \ldots, X_k)/z \epsilon E^k \text{ and } z = \sum_{i=1}^{N} \lambda_i V_i \text{ with} \qquad (3)$$

$$\lambda_i \geq 0 \text{ and } \sum_{i=1}^{N} \lambda_i = 1\} \text{ where } E^k \text{ represents the k-dimen-}$$

sional Euclidean space.

The behaviour of the regression function in the area C is now of importance because the area represents all combinations of data points observed.

Suppose the influence of a specific decision variable, for example X_p, on the dependent variable is studied. In the first place it is necessary to know the area of variation covered by X_p within the available data. In this project the data were derived from a 7-point scale so that the minimum values which may be attained for all the variables are 1 and the maximum 7.

If we let $X_p = q$ where $q \epsilon (1,7)$, it would be desirable to determine the values of the remaining decision variables so that S could be a maximum or a minimum. To be able to do this, the following linear programming problem was formulated:

$$\underset{(\min)}{\mathrm{Max}}\ S = b_0 + b_1 X_1 + \ldots + b_k X_k \qquad (4)$$

(where b_i = the regression coefficient for variable X_i) subject to the following constraints:

$$\sum_{i=1}^{N} \lambda_i X_{ij} = X_j \geq 0 \text{ for } j = 1, \ldots, k$$

$$\sum_{i=1}^{N} \lambda_i = 1, \quad \lambda_i \geq 0 \text{ for } i = 1, \ldots, N$$

$$X_p = q.$$

The solution of the linear programming problem then yields the maximum (minimum) of S as well as the levels of the decision variables $X_1, X_2, \ldots, X_k$, where this optimal level is reached. By solving this problem for various values of q in the interval (1,7), the maximum and the minimum values of S may be determined together with the optimal levels of the remaining decision variables.

The above solutions may be obtained by using parametric linear programming techniques (7). In this project, however, a linear program was developed in which q was incremented from 1 to 7 in steps of 1 for each of the "independent" variables.

Note that the difference between the maximum and minimum values of S at any level q of X_p is an indication of the influence of the remaining decision variables on S. This influence is relatively small (large) when the difference is small (large). In the above discussion only one decision variable X_p was restricted at a particular level and the linear program solved, but it is of course possible to restrict more than one decision variable at specific levels and then to solve the linear programming problem.

In this project this technique was applied and graphic

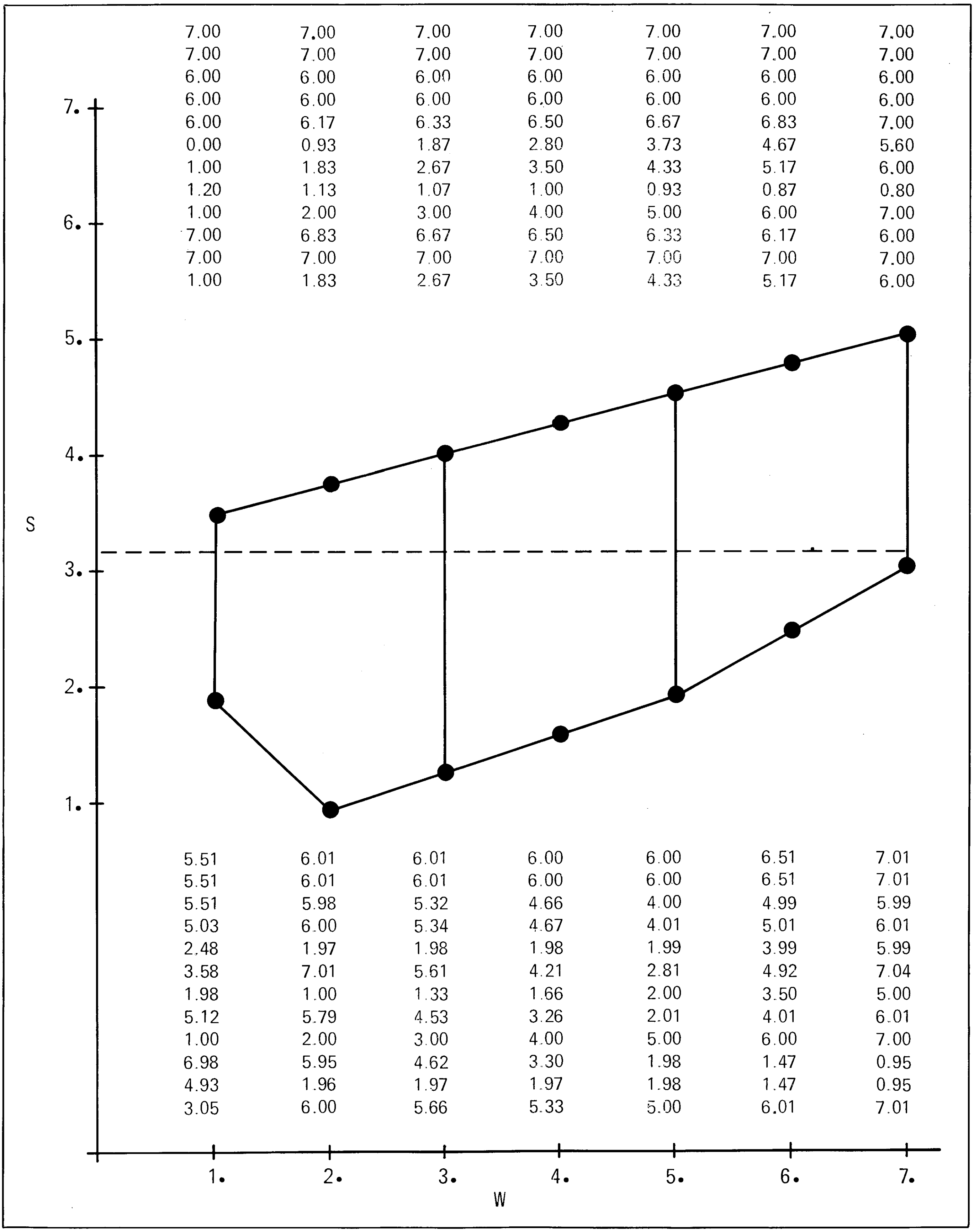


FIGURE 2: Maximum and minimum values of dependent variable S.

representations obtained for each of the 12 "independent" variables together with the optimal values of the decision variables when one variable at a time was restricted to the values 1,2,...,7. Figure 2 is an example of such a graphical representation. In this figure the numbers above represent the optimum values of the decision variables when the objective function is maximized while the numbers below represent the values of the decision variables when the same objective function is minimized.

With the aid of these solutions and graphical representations five factors which have significant influence on the success variable could be identified. These factors are the following:

— Accuracy of the information yielded by the systems.
— The availability of resources.
— The term of service of a manager within the organization.
— The technical quality of computer personnel.
— Training provided for users of the information systems.

One of the factors, viz. the term of service of a manager within the organization, can be regarded as a state variable (not totally under management control).

4. Cost Models

Although the cost involved in all eleven variables (excluding the state variable) is of significance when the success has to be improved, the four above are those which should preferably be given attention. For the management of an organization it is important to know how to apply available funds in order to maintain the success of the systems at a desired level of efficiency. The basic problem is of course the fact that the cost involved in increasing the levels of the various variables would differ in the different instances. The availability of capital is another limitation on the expansion of the variables. Suppose the total amount of capital which may be applied for computerizing purposes (that is, capital already spent plus capital available for further expansion) is R Rand. Suppose further the costs involved in raising variables $X_1, X_2, \ldots, X_k$ by one unit on the 7-point scale are $Q_1, Q_2, \ldots, Q_k$ Rand respectively. By using R and the Q's in a cost-restricting equation in a cost model in which one or more state variables are restricted to specific levels, the optimal values of the decision variables and the objective function values may be obtained by solving the linear programming problem for various values of R.

The cost model is the following:

$$\text{Max } S = b_o + b_1X_1 + \ldots + b_kX_k$$

subject to the following constraints: (5)

$$\sum_{i=1}^{N} \lambda_i X_{ij} = X_j = 1,2,\ldots,k$$

$$X_p = q$$

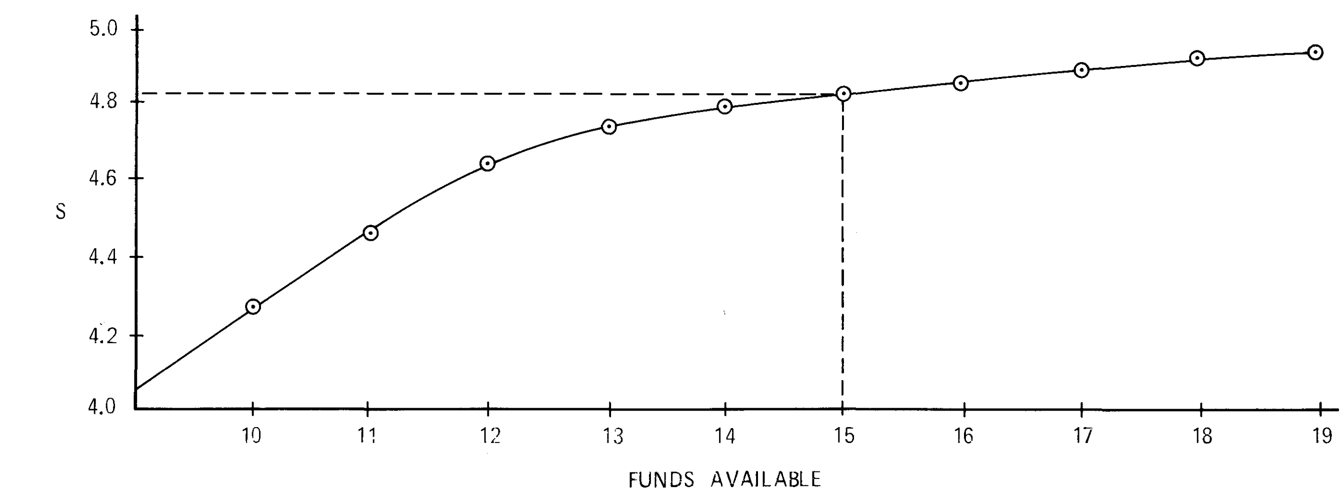
$$\sum_{i=1}^{N} \lambda_i = 1$$

$$\sum_{j=1}^{k} Q_jX_j \leq R, \ \lambda_i \geq 0 \text{ for } i = 1, 2, \ldots, N \quad (6)$$

To demonstrate the model hypothetical costs were used and the linear programming problem solved varying R from 1 to 20 units in steps of 1. Figure 3 gives an indication how the success could be improved with more funds available. The table in this figure represents the values of the decision variables when the objective function (in this case the term of service of a manager) is restricted to a certain level. The difference between these values and the current values of the decision variables gives an indication how much the decision variables have to be raised to obtain the corresponding level of success of the system represented in the graph. When a single computerized system has to be improved, the simple cost model may be fruitfully applied. When more than one system is considered, this model may be applied in an iterative sense.

A GENERAL COST MODEL

Suppose the level of a variable X_j is a result of levels of its



OPTIMUM VALUES OF DECISION VARIABLES FOR MAXIMUM

A =	2.7	3.3	4.0	4.7	5.2	5.5	5.8	6.2	6.5	6.8	7.0
E =	5.1	5.1	5.1	5.0	5.2	5.5	5.8	6.2	6.5	6.8	7.0
C_1 =	3.3	4.0	4.8	5.7	6.0	6.0	6.0	6.0	6.0	6.0	6.3
C_2 =	3.3	3.2	3.1	3.0	3.3	3.8	4.3	4.7	5.2	5.7	6.3
C_3 =	5.9	6.0	6.0	6.0	6.1	6.3	6.4	6.6	6.7	6.9	7.0
H =	.4	.3	.2	.1	.6	1.6	2.5	3.5	4.5	5.4	6.3
T =	2.3	2.5	2.7	2.9	3.3	3.9	4.4	4.9	5.5	6.9	7.0
W_1 =	4.4	5.3	6.4	7.0	7.0	7.0	7.0	7.0	6.7	6.5	6.5
W_2 =	2.5	3.8	5.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.7
W_3 =	1.3	2.4	3.5	4.6	5.1	5.3	5.6	5.8	6.0	6.2	6.5

FIGURE 3: Improvement of success with more funds available.

components represented by the variables $Y_{j1}, Y_{j2},\ldots, Y_{j\ell}$. Suppose further the variable X_j represents the availability of resources. These resources consist of certain basic components such as power of the central processor, disc space, software, etc. The level of X_j may be raised by improving some of the components or perhaps all of them. The problem is complicated by the fact that the source components may be shared by different computerized systems.

A general cost model in which the contribution of the source components to the level of a specific variable is considered and in which provision is made for a number of systems to be improved simultaneously may be formulated as follows:

Let $X_i^j = \sum_{\ell=1}^{\ell_i} f_{i\ell j} Y_{i\ell}$ be the j-th variable influencing the success S_j of computerized system j, where $f_{i\ell j} \geq 0$, for all i,j and ℓ, with $\sum_{i=1}^{\ell_i} f_{i\ell j} = 1$ and ℓ_i the number of components Y_i of variable X_i^j. (7)

This linear relationship implies that X_i^j will be on its maximum level (level 7) when $Y_{i1},\ldots,Y_{i\ell_i}$ are all on the maximum level.

Suppose an organization wants to spend R Rand to improve the success of its computerized systems. The level of each variable X_i^j can be measured like it was done in [3]. The weights f_{inj} for each of the source component's contribution to the level of variable X_i^j could be estimated by the organization. The present level of the source components Y_{in} can be estimated by using the non-linear least squares method of Gauss-Newton ([5], p. 808) by minimizing the quadratic relationship.

$$\sum_{j=1}^{p} (X_i^j - f_{i1j}Y_{i1} - f_{i2j}Y_{i2} - \ldots - f_{i\ell_i j}Y_{i\ell_i})^2 \tag{8}$$

for each variable X_i^j where i = 1, 2,...,k. This can be done by using a computer program ([5], p. 464). To be able to interpret the estimators it is desirable to restrict their values between 1 and 7. Suppose $V_1, V_2,\ldots, V_p$ are the levels of success we want to achieve for the p systems. Consider the following objective function to be minimized:

$$z = \sum_{i=1}^{p} a_i | V_i - b_0 - \sum_{t=1}^{k} b_t X_t^i \tag{9}$$

where k is the number of variables and a_i a weight associated with each system to be improved. This objective function is subject to the following constraints:

$$\sum_{p=1}^{N} \lambda_p^i X_{p\ell}, X_\ell^i, X_j^i = q_i,$$

$$\sum_{p=1}^{N} \lambda_p^i = 1, \text{ for } i = 1, 2,\ldots,p \text{ and } \ell = 1,\ldots,k. \tag{10}$$

$$\sum_{s=1}^{\ell_i} f_{isj} Y_{is} = X_i^j \text{ for } i = 1,\ldots,k \text{ and } j = 1,\ldots,p.$$

We may assume the number of components of variable X_i^j is independent of j because a weight of zero is allowed.

Substitution of (10) in (9) yields

$$z = \sum_{i=1}^{p} a_i | V_i - b_0 - \sum_{t=1}^{k} b_t \sum_{n=1}^{\ell} f_{tni} Y_{tn} | \tag{11}$$

In the same way the general cost model can be formalized to

$$\text{Min} \sum_{i=1}^{p} (C_{i1} + C_{i2})/a_i$$

subject to the following constraints: (12)

$$V_m - b_o - \sum_{t=1}^{k} b_t \sum_{n=1}^{\ell_i} ft_{nm} Y_{tn} + C_{m1} - C_{m2} = 0$$

$$\sum_{j=1}^{N} \lambda_j^m X_{ji} - \sum_{n=1}^{\ell_i} f_{inm} Y_{in} = 0$$

$$\sum_{n=1}^{\ell_i} f_{inj} Y_{in} = q_i \text{ for all j}, \quad \sum_{r=1}^{N} \lambda_r^m = 1,$$

$$\sum_{i=1}^{k} \sum_{g=1}^{\ell_i} (k_{ig} Y_{ig}) \leq R \text{ where } i = 1,\ldots,k \text{ and } m = 1,\ldots,p.$$

REMARKS

1 In the objective function (12) C_{i1} and C_{i2} were used to allow positive or negative differences between the levels we want to achieve and the linear function determining the success of the system. C_{i1} represents a negative difference and if it appears in the solution on a positive level it means that the success levels we want to achieve are exceeded. This means C_{i1} may be deleted from the objective function because a solution better than those we want to achieve should not be penalised.

2 The level of variable X^j (for each system) is restricted since.

$$X_i^j = q_i \text{ or } \sum_{n=1}^{\ell} f_{inj} = q_i.$$

If more such variables should be restricted, additional constraints can be used.

3 In this model R can be varied. This will allow one to see exactly how R influences the improvement of success. A low value of R will typically imply that the success levels we want to achieve for the different systems cannot be reached. Higher values of R will allow the model to achieve higher levels of success.

5. Conclusions

Although a number of researchers have investigated success and failure patterns in computer-based information systems in the past, it is still not easy for the management of an organization to improve the quality of their systems by using the results obtained.

In this project a procedure was developed which could be quite useful for the management of an organization when the performance of the computer-based systems is poor. This procedure requires knowledge of statistical and linear programming techniques. Whenever the management of an organization follows the outlined procedures they will not only be able to pinpoint the most critical problems affecting the success of the computer-based systems in the organization, but the cost models developed will allow them to apply available funds in an optimal way to solve those problems.

ACKNOWLEDGEMENT

The author wants to thank Prof. J.M. Hattingh, Department of Statistics and Operational Research, Potchefstroom University and Prof. H. C. Lucas jr., Graduate School of Business Administration, New York University for their comments and useful hints.

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Contents/Inhoud

*Presented at the second South African Computer Symposium held on 28th and 29th October, 1981.