Journal of Business
Administration and Information
Vol.16 No.1 (2008), pp33-47

Research Paper

A Theoretical Approach to the Optimal IT Investments — Application of the Genetic Algorithms

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【Summary】 In the study of economy it is the world tendency that more and more attentions are being paid to the intangible assets. In these few years many movements of studying, measuring, reporting intangible assets have appeared[1,2,3,4]. Also in the field of IT(Information Technology)-investment, it is well known that for the effective IT investment, considerable amount of fund should be invested in the improvement of human resources and in management systems of their own companies. And these management should be accomplished continuously; from the plan, throughout the execution of it, to the monitoring the results of investments. These process are called IT investment management(ITIM). IT investment management must include the intangible assets in its field of activity. There are many parameters considerable that will influence IT investment evaluation. These mechanisms are fairly complicated to describe systematically and be analyzed by means of usual mathematical tools such as dynamic programming. However, for the effective investment it is important to understand the mechanisms of how the revenue or added value can be made up throughout investments. This paper is an attempt to theoretically describe this mechanism and to find out the optimal results. For the last object using genetic algorithms (GA) is proposed.

keyword : IT investment management, intangible assets, genetic algorithms.

1 Introduction

Most of enterprises are paying much attentions in investing IT equipments, specially in computernetwork related apparatus, since they are making rapid and large developments these days. Moreover, as is well known, they are giving great influences on economical activities. On the other hand, it is a matter of fact that computer environment do not work well if they are not operated properly and are not managed properly. To make the IT environment work properly, the human ability to utilize them must be equipped. This means, if the investment is not guided properly to introduce such environment, these equipments do not work well. Notwithstanding these situation, how much should be invested to make up those circumstances is not clear. For the optimal investment, measuring the present ability of utilizing the environment which are making up revenue is the fundamental subject. Now these ability consist of the main part of so called intangible assets and measurement of it is becomming a great concern. According to Brynjolfsson[5] to make the total IT-related investment work properly, about 7 to 10 times of direct IT investment are needed for the intangible assets of IT-related. Theoretical analysis and formulation of the mechanisms of the investment are the basic subjects to find the optical investment.

2 Background

Specially from the latter half of 1990's, the number of reports indicating the importance of the intangible assets has rapidly increased. It is said, although with some exaggeration, today is the times of intangible assets. In some report it is said in the average 70 % of assets of firms are intangibles at present day, although only 30 % in 1930's. Note the following rather exciting description in the report by Jarboe[1]

"American businesses, investors, regulators and policy makers are **flying blind**. The United States is now in an intangible economy, but financial reporting and accounting systems can't deal with intangibles.・・・as a consequence, business, investment and economic policy decisions are being made"in the dark"". "The value of U.S. gross investments in intangibles has been estimated to be at least a **trillion dollars** annually, covering investments in R&D, advertising and marketing, software, financial activities and creative activities of writers, artists and entertainers."

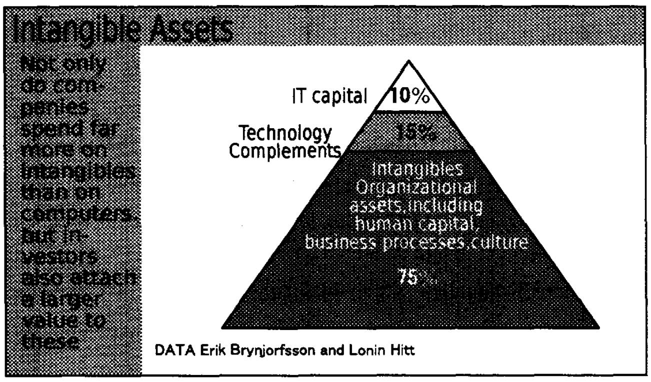


Figure 1: Brynjolfsson's Estimation

On the importance of investing intangibles in also IT region, Brynjolfsson[5] pointed out that more than 75% of assets concerning IT should be intangibles. He showed the above Figure 1. Although the importance of the intangible assets are becoming well recognized, the estimation of the income caused by the intangible assets or even measuring intangible assets itself is very difficult. Today, researchers are only beginning their study how to measure intangible assets properly after noticing the necessity of reporting those in each firms. These situation can be seen in [9, 10].

3 Estimation of the Revenue

Also although it is a great concern how the intangible assets work in making value, only a few results are obtained on the mechanism of this system.

Lev developed in his energetic works investigating the reports of large number of companies a method to estimate the effects of intangible assets in making up the revenue of firms. He classified companies into 20 classes and for each class, many companies are chosen[3]. As the results he investigated more than 1000 companies. He showed the results in the following estimation. It should be noticed that he claimed a patent to this equation.

3.1 Brauch Lev's Method

Brauch Lev's estimation[3] is as follows. Let *Ep, Pa, Fa, Ia* denote economic performance, physical assets, financial assets and intangible assets, respectively. Then the economic performance is obtained by the following equation,

$$Ep = \alpha(Pa) + \beta(Fa) + d(Ia). \quad (1)$$

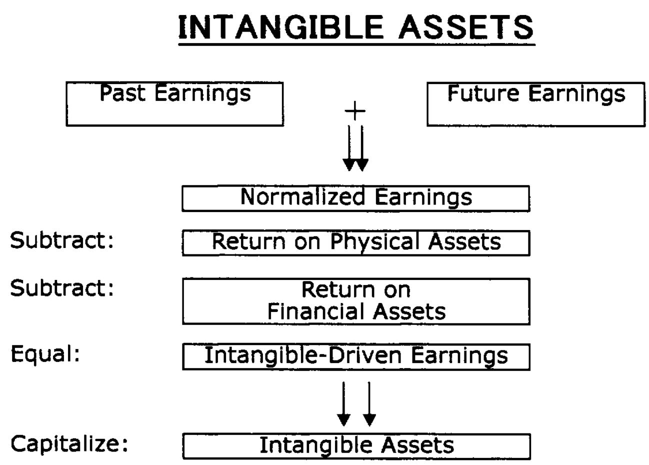


Figure 2: Lev's Estimation

(note) in his work, the definition of the economic performance Ep is not clearly given.

In the equation (1), α, β, d represents the contributions of a unit of each asset to the enterprise's economic performance. Note that the kind of characters of coefficients of physical assets, financial assets and intangible assets are different. The first α, β, are greeks and the other d is a roman. This fact indicates that the characteristics of these parameters are different. α and β are derived from the analysis of the data of past performance and d is calculated with the help of α and β. Lev calculated these parameters as is shown in Figure 2.

3.2 Problems on Lev's Method

Lev paid much efforts to construct his equation. However, at the time of newly investment, it is soon recognized that his equation is not applicable. Let a firm's Ep is giben by (1). Now assume this firm decided to invest certain fix amount Δq on the top of the present amount q. Then what amounts must be alloted to tangibel, intangible of assets. Let ΔTa, ΔIa, ΔFa be the corresponding amounts of tangibel, intangible or finantial assets. Then theny must satisfy the relation,

$$\Delta q = \Delta Ta + \Delta Fa + \Delta Ia. \tag{2}$$

By increasing these amounts of investment, assume ΔEp is obtained as an increments of the revenue. Then ΔEp must satisfy,

$$Ep + \Delta Ep = \alpha(Ta + \Delta Ta) + \beta(Fa + \Delta Fa) + d(Ia + \Delta Ia). \tag{3}$$

Subtracting (3) from (1), we obtain,

$$\Delta Ep = \alpha(\Delta Ta) + \beta(\Delta Fa) + d(\Delta Ia). \tag{4}$$

Thus, the problem to be considered is to find the set of ΔTa, ΔFa, ΔIa which maximize the ΔEp, satisfying the relation (3), under the restriction of (2). This is a problem of simple linear programming, and the solution is readily obtained as follows.

We assume for the simplicity no two parameters of α, β, d are equivalent, and safisfy

$$\alpha > \beta > d. \tag{5}$$

Then the maximum ΔEp is given by

$$\Delta Ep = \alpha(\Delta Ta + \Delta Fa + \Delta Ia) = \alpha(\Delta q).$$

Even if the order of α, β, d are different to (5), a similar result is obtained.
The obtained conclusion in such case is as follows.

"Invest all the fund to the one special kind of asset which have maximum expected return."

This is no more the problem of allocation of funds into several assets. This can not be the realistic answer to be obtained. The conclusion obtained from this consideration is that,

"It is difficult to use Lev's equation as a guide to obtain the maximum outcome of the allocation of investment into several kinds of assets".

A different equation must be considered.

4 Construction of Nonlinear Relation

It is a common knowledge that the funds should be allocated into several assets to obtain the maximum results of the investment. Then, what is wrong in the Lev's equation? The reason is the nonlinearity. That means that there must exists some expression describing some mutual effects of these assets to produce the revenues of the investment. These relations should be described by a nonlinear terms and these nonlinearity should be took into consideration. However, what kind of nonlinearity should be considered? Unfortunately, it is not clear how these assets work out the profit. There have been accomplished several works on this points. On the other hand, it is shown in the report of L.C.Hunter et al[4] that "In practice, most of these espoused measurement system assume causal relationships rather than validate them with robust empirical evidence."

However, without estimating the relation, any firm can not decide the investment. There must exist some estimation always, although it is not recognized clearly. As a results of these consideration and estimation, the following conclusions must be reduced.

"A proper nonlinear funciton must *be constructed* for each firm to make clear the results of it's investments."

4.1 Trial of constructing a nonlinear function

Here we begin a basic study of constructing this nonlinear function. For the simplisity we only consider tangible assets and intangible assets in what follows. Let $f(x, y)$: $R^{+2} \rightarrow R^{+}$, denotes the nonlinear function describing the economic performance as a function of tangible assets, $x \in R^{+}$, and intangible assets $y \in R^{+}$, respectively. Then $f(x, y)$ must satisfy several assumptions. which are listed below.

1. $f(x, y)$ is a piecewise continuous function of x and y.
2. $f(x, y)$ is a monotone increasing function of x and y.
3. $f(0, 0) = 0$
4. $f(\cdot.\infty) < \infty,\ f(\infty,\cdot) < \infty$
5. $\max f(x, y)|_{x+y=a}$ increase as a increase. This indicates that if the total amount of the investment increase then the optimal results must increase accordingly.

6. $f(x, y)$ might have some discontinuous points, which indicate certain jump effects of the investment. (As a matter of fact such effects are reported in the results of investment quite often.)

With the help of such function $f(x, y)$, we can formulate the problem to be considered as follows.

Problem to be considered

Find the

$$Ep = \max f(x, y)$$

under the restriction

$$x + y = a \quad (a : constant).$$

That means if the total amounts of funds are given as a, the problem is to find the best allocation of a into x and y to maximize the final gain Ep. Where x, y denote tangible and intangible assets, respectively.

4.2 Some candidates of nonlinear functions

In their pioneering work [7], Amir M Sharif et.al. proposed to use a transcendental functions to describe the effects. Although their approach is not clear and difficult to follow, their proposed functions are as follows. Let IJ, DC, ID, SM, T_L denote the investment justification, direct cost, indirect cost, medium term strategic outcome and lead time of starting DC to SM. Then they are given as

$$DC = \tanh t,$$
$$IC = 4\tanh t,$$
$$SM = 1 - \exp(\log(\frac{1}{t})) + a,$$

where t indicates time and a is a constant which locates SM above the positive quadrant x-axis and IC should be generally 4 times greater than DC. They claim that by using these parameters IJ is given as

$$IJ = \min \{IC, T_L\} + \max \{SM\} \tag{6}$$

and finally it is given as

$$IJ = \min \{\exp \frac{1}{t} (16\tanh(t) + (1 - \log \frac{1}{t}) + a)\} \tag{7}$$

In their report the reason of this IJ is not clearly given. It is rather difficult to follow their estimation.

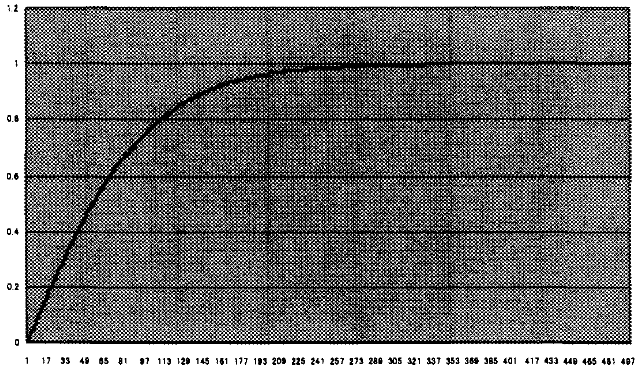


Figure 3: shematic view of tanh

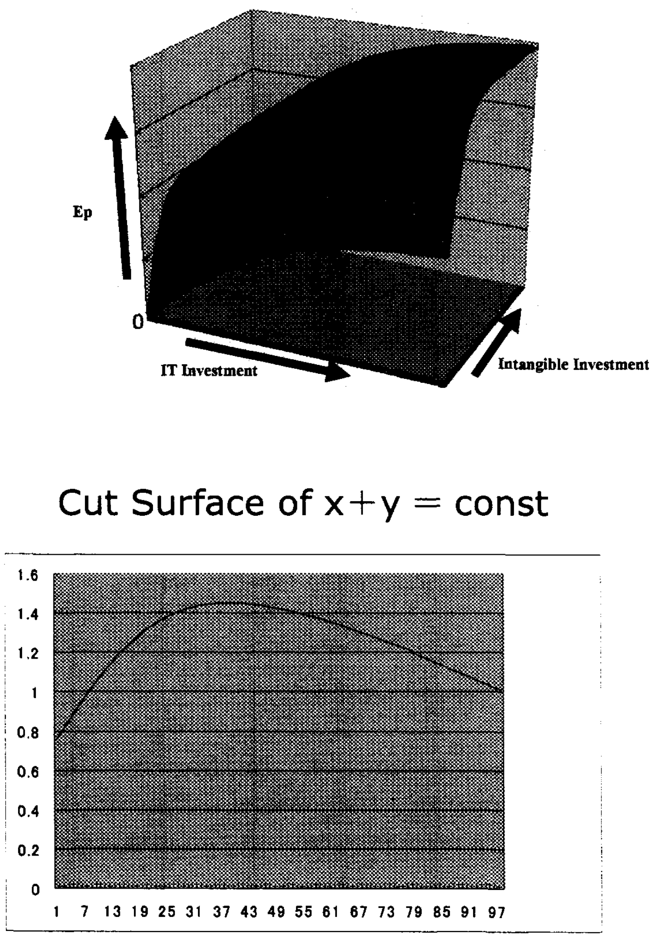
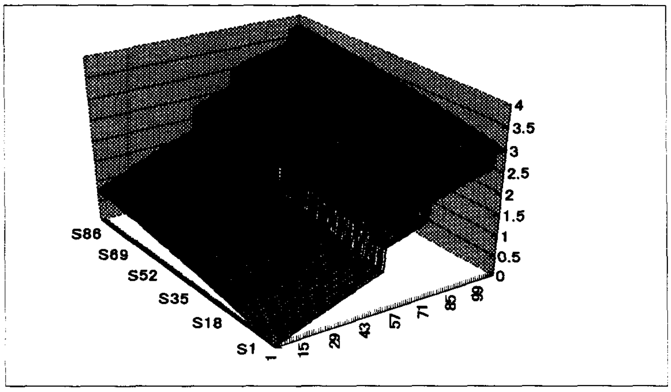


Figure 4: shematic view of function tanh $x \cdot$ tanh y and cut surface by $x+y = a$



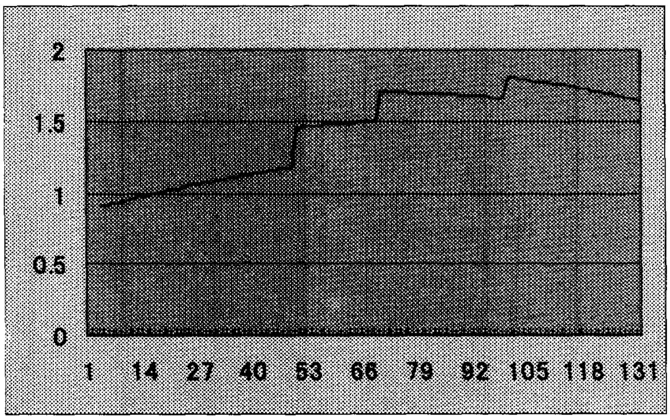


Figure 5: shematic view of function with jumping effects

Following their example, it is tried to use tanh-function.
In case $f(x, y)$ is given as

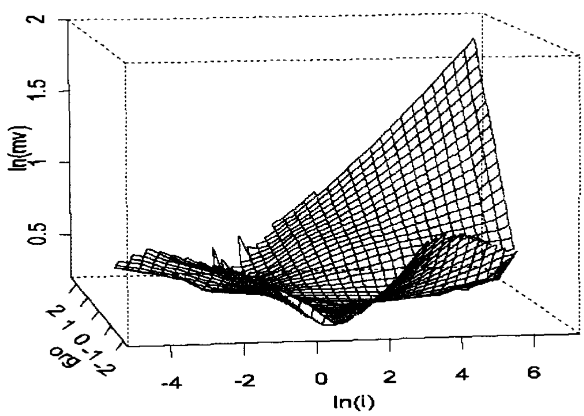
$$f(x, y) = \tanh(x)\tanh(y), \tag{8}$$

The estimation is shown as in Figure 4. In this case the cut surface of the curved surface by the plane $x + y = a$ (constant) is shown in the lower one of Figure 4.

In case that some jumping effects occurred in the investment then the figure and cut surfase are shown as Figure 5.

4.3 Brynjolfsson's function

In his book Brynjolfsson[5] presented the results of his research on the effect of direct IT assets and organizational assets which were given in the the following Figure 6. This figure can be thought as a experimental results of the investment. This figure shows some interesting feature of the investment. The final results shows a depression as the growth of direct investment when a organizational assets are small. It is usually said true if the knowledge level is low, the over investment cause rather a depression some times in the final results.



In represents computer capital, *org* represents ameasure of decentralization and *mv* is market value.

Figure 6: effect of direct investment and regional effect

4.4 Considerations on the productivity and efforts

To mathematically describe the relations between the productivity and efforts(man power or fund) is extremely difficult. However, there exist a few researches attempted it. In relation to the efficiency of the investment the researchers of Great Britain developed the following estimation of the productivity of the investment. Their estimation is as follows.

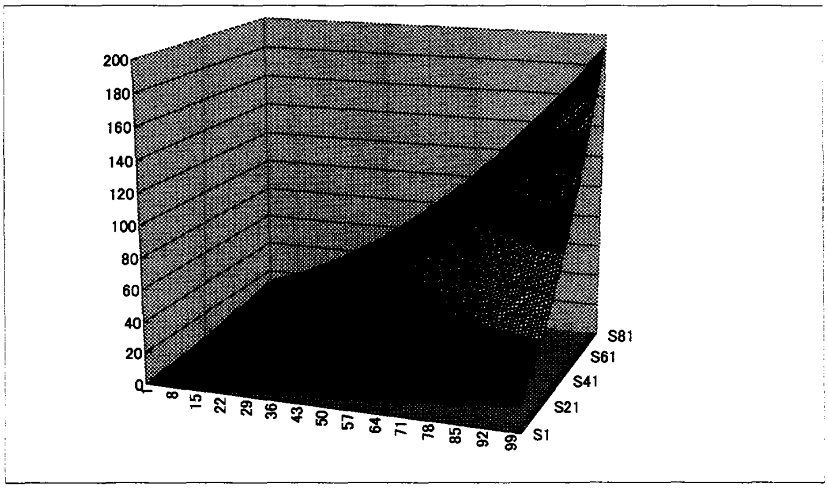
Let *added value* is denoted as Y then Y is given as

$$Y = \text{sales} - \text{cost of inputs}.$$

Basic model is that Y depends on capital K, labour L and technology A, where this includes all 'expertise and innovativeness' of a firm. As a result Y is given as

$$Y = AL^{\alpha_1}K^{\alpha_2} \tag{9}$$

where $\alpha 1$ and $\alpha 2$ are certain fixed constants. Figure 7 indicates this relation in the case that $\alpha 1 = 2$ and $\alpha 2 = 1.5$. The curve of the lower part of Figure 7 is the cut surface of this figure by the plane $K + L =$ constant. It should be noted that if α 1 and α 2 are thus fixed, then the figure has some resemblance to the figure given by Brynjolfsson. The relation between the two equation (4) and (9) and the relations between parameters as α, β of (4) and α 1 and α 2 of (9) are not clear. However, by applying Taylor expansion to (9), similar equation as (4) is obtained.



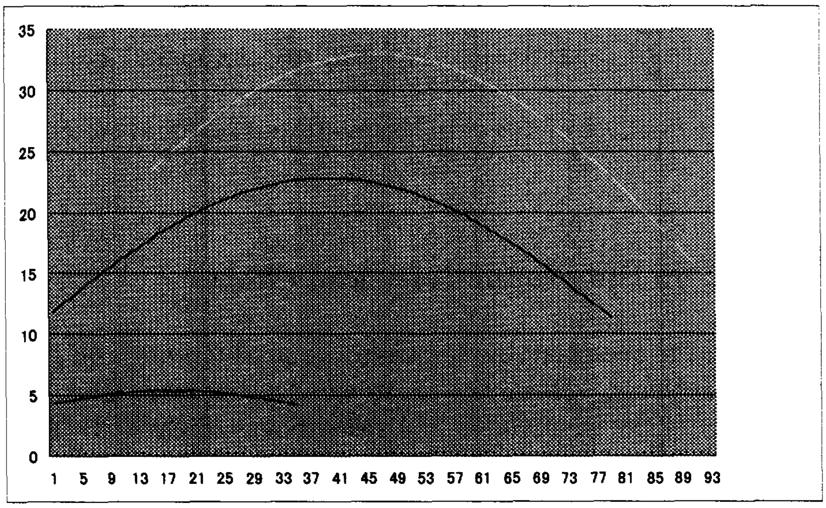


Figure 7: shematic view of $Y = AL^{\alpha 1}K^{\alpha 2}$, $\alpha 1 = 2$, $\alpha 2 = 1.5$ and cut surface by $K + L = a$

5 Application of the Genetic Algorithms (GA)

After viewing some candidates of nonlinear functions, now we come back to the problem shown in 4.1. Finding the maximum point of the curve is not easy if the curve have some jumping points. To such problem the application of the genetic algorithms seems to be efficient. Genetic Algorithms is the method to find the maximum point of a function by utilizing the procedure of the evolution in nature. It is fairly different way of searching maximum points to the usual mathematical methods. The followings are the supposed efficiencies of Genetic Algorithms in the application to such kind of problems.

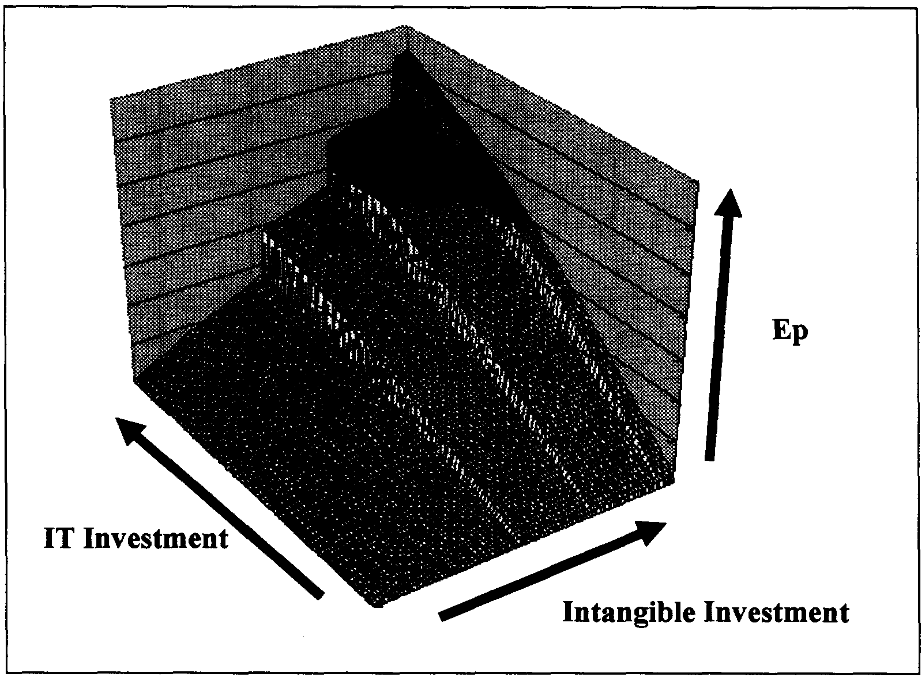
1. GA can cope with many kind of nonlinear functions, without much change of main algorithms. In the application of GA, we have only to decide the value of functions at certain chosen points. Therefore, in changing the form of functions do not cause much troubles.

2. *Ep* might be a very complicated function, sometimes even not differentiable. As is shown before, in the application we only need the vlaues of the functions, whereas so far utilized mathematical method need the differentiability of the functions.

3. Sometimes *Ep* can not be described mathematically. Only several values of sample points are empirically given.

4. Policy making can take time and severe accuracy is not required. GA is often said it take time to obtain the results and the result is not very accurate. However, these are not usually required in the IT invest managements. We can spare few minutes for the decision always.

Cut Surface of x+y = constant



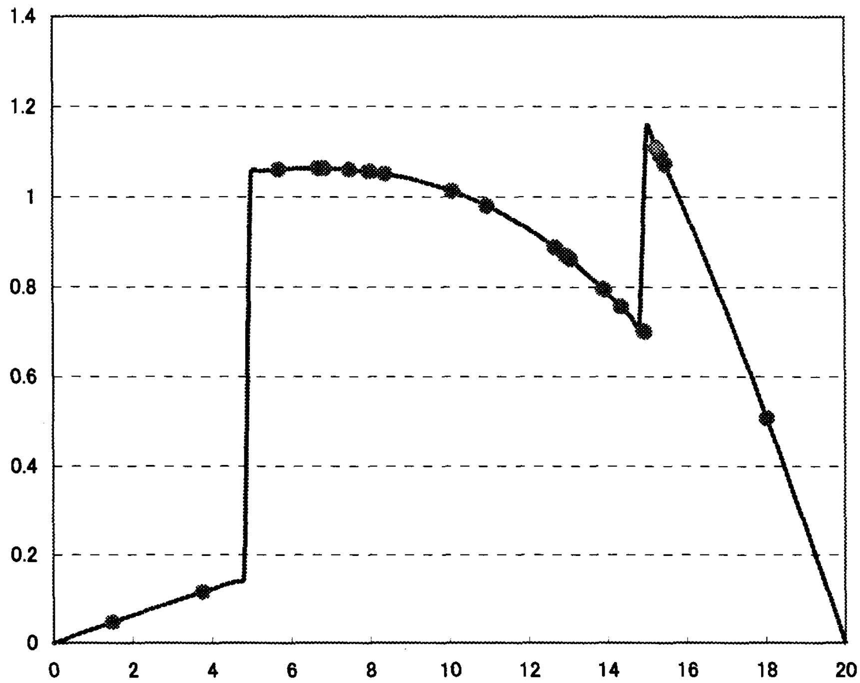


Figure 8: Example for the caswe $Ep = \tanh(x/10) * ((20-x)/30 + \mathrm{round}((20-x)/10,0))$ and cut surface by $x+y = 20$

6 Example of the application of GA

The following is the example of the application of GA. The performance is assumed to be determined by the function,

$$Ep = \tanh(x/10) * ((20-x)/30 + \mathrm{round}((20-x)/10,0)) \tag{10}$$

This shows there can arise a unitstep effect in the investment of intangible assets. This reflects the general view point that the investment in the education often causes jumping effects. The cut surface is given as

$$x+y = 20$$

Although this example is fairly simple and overemphasize a certain aspect of the investment, the results shows a interesting feature. The above figure also indicates the results of the application of GA to this example and the marked points indicate the intermediate results of the application process. It is shown that although the marked points are scattered on the curve considerably, the final results shows the good estimation of the maximum points.

7 Some Consideration

The obtained figure is a very special case of the relation between investment and their effects. However, we can see some interesting feature of IT investments. The figure shows a deep depression of the total revenew as the direct investment increase. This indicates that there exists cases that although the direct investment increases, (the indirect investment (invest to intangible assets) decrease), the total revenew decreases. It is often said that such situations arises when new machines are introduced. That means that if enterprises introduce new environment, it is necessary to invest to educate workers sufficiently to make the full use of these new environment. If such are not done, the new environment cause large negative effects. The optimal allocation of funds are necessary and there must exists the optimal points. Although in this example, the optimal opint is unique, this is not necessarily every case.

8 Conclusion

The application of the theoretical method to the optimization of IT-investment is considered. Although the situation of the research is very primitive, it was found the some typical phenomena can be explained theoretically. The nonlinear functions utilized here are estimated through theoretical consideration. These functions are much more complicated in reality and different to each kinds of firms and scale of each firms. Actually they should be constructed and polished by each firms individually. Though it seems fairly difficult task, it might be needed in the future in each firms.

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Appendfix

A Few More Details of the Application of GA

A.1 General Comments

In this appendix a few more details of the application of GA in Sec.6 are presented briefly. GA is a new method to find the optimal value by applying the artificial method of the Dawininan evolutional processes in the nature. GA was introduced by Holland[13] and developed by Goldberg et al[14]. After the introduction this method has been developed dramatically and is being applied successfully in many kinds of problems.

In the nature every living creature contains their unique genes in chromosomes and deriver them to the next generation after crossing over with those of their partners. And with them the next generation start. Some time mutations happen and new species appear. Among the limited number of the members of the same species in certain generation, stronger ones have many chances to leave their descendants. These are the brief view of the mechanism of the survival of the fittest during the generations in the nature.

GA simulates these processes artificially to find the optimal values. To do this, some kind of artificial chromosome (they are called strings in GA) and the evaluation mechanisms of them are needed. For the application to our problem, making out genetic systems and evaluation mechanisms are rather easily accomplished. As for strings, the numerical expressions of investment are used and as for genes numerical digits of the string are utilized. The evaluation of them the equation (10) can be adopted.

The followings are the parameters for GA of the example in Sec.6.

A.2 Parameters

(i) number of the population: 30
(ii) number of the generation: 100.
(iii) gene system: the numerical expression of x. $0 \leq x \leq 20$.
(iv) point of crossover: fixed.
(v) crossover rate: 0.65
(vi) mutation rate: 0.05.
(vii) evaluation equation: (10).
(viii) choosing the survival candidate: roulette method
(ix) number of elite: 2

A.3 Results

The results are shown in the bottom one of Figure 8. Although the form of the function is fairly complicated, the maximum point was found in almost every tiral with sufficient accuracy after 100 generations.