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Investigation on Relationship between Cost and Software Reliability

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Abstract: Based on the fact that the software development cost is an important factor to control the whole project, we discuss the relationship between the software development cost and software reliability according to the empirical data collected from the development process. By evolutionary modeling we get an empirical model of the relationship between cost and software reliability, and validate the estimate results with the empirical data.

Key words: cost controlling; software reliability; software development cost; empirical data; evolutionary modeling

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0 Introduction

When software product is still on design, the reliability of the complete system should be set. But if we want to minimize the development cost of the system, how much should each system module reach to meet the requirement on the system reliability? This is the problem that the software reliability allocation intends to solve[1-8]. Software reliability allocation develops gradually in recent years; however, many allocation methods allocate reliability to software module without considering the cost of it [2], despite the cost is important to software controlling.

At present, we have collected some empirical data about the relation between software development cost and software reliability, to make full use of it to investigate the relation sounds meaningful.

In this paper, we discuss how to investigate their relationship with these data. According to this relationship, an empirical model of cost and software reliability is set up.

Due to the difference of module size and design, the feasibility of improving each module's reliability is also different, the more difficult to improve, the more development cost is needed. Thus, when allocating reliability, the feasibility of improving module's reliability is also an important factor to consider [9].

1 Empirical Data of Software Development Cost and Software Reliability

Nathematical symbols used in this paper:

C_i: The development cost of module i;

R_i: The reliability of module i estimated by reliability model;

$R_{i.\min}$: The minimum reliability that module i can accept;

$R_{i.\max}$: The maximum reliability that module i can reach;

R_s: Software reliability;

f_i: The feasibility of module reliability improvement, $0<f_i<1$.

During the long period when we do research on software reliability, we have collected a lot of empirical data from many cooperative corporations, some of them are data about software development cost, and some are fault data about software development project. With these fault data, by using software reliability models such as Weibull model, NHPP model[10,11] and so on, we can estimate the current reliability of the software conveniently.

There is some relationship between software development cost and software reliability. People had stuck on theoretical and qualitative research on this relation before, without investigating it quantificationally. Now, we want to investigate their quantitative relation quantificationally by using these empirical data.

With the empirical data about software development cost, for simplifying the discussion, transfer the cost to a positive integer e. g. assume per hundred thousand Yuan to be a cost unit.

In this model, there are two relations needing confirmation. One is relation between R_s and R_i, the other is relation between C_i and R_i. So, the formula of the system reliability related to these module reliabilities is very important. In simple systems, modules connect together serially and independently, thus the system reliability is the product of the reliability of each module. However, in complex system, as relations between modules are complicating, the system reliability is not the product of the reliability of each module any more. As to how to confirm the relation between R_s and R_i, it is closely related to the concrete system. There is detailed discussion in this respect in Ref. [12-14].

The relation between C_i and R_i is used to reflect the relation between module development cost and module reliability for mainly, which is called cost estimate function $C_i(R_i)$. If $C_i(R_i)$ isn't confirmed, then R_i cannot get confirmed to minimize the system development cost C. There are many methods to confirm the relation between C_i and R_i, one direct method is according to the empirical data, which were collected from a development project in a software company.

Some empirical data are showed in Table 1.

Table 1 Empirical data

f_i	R_i	$R_{i.\min}$	$R_{i.\max}$	C_i	Cost estimate C'_i
0.0	0.80	0.950	0.995 0	2.25	2.15
0.1	0.75	0.975	0.999 5	2.35	2.25
0.2	0.75	0.950	0.995 0	2.20	1.92
0.2	0.70	0.950	0.999 5	2.00	1.94

(Note: Set $f_i=0.0$, indicating not considering the feasibility of module reliability improvement; C_i denotes the rounded development cost of module i.)

By analyzing all the factors influencing C_i and formulating C_i with these factors, the relation between C_i and R_i is confirmed. With the empirical data we collected before, after evolutionary modeling[15,16] experiment, we find that the relation between C_i and R_i satisfies the cost-reliability model below:

$$C_i(R_i; f_i, R_{i.\min}, R_{i.\max}) = Ae^{XY} \tag{1}$$

where A is a positive constant, whose value can be adjusted according to the concrete situation. A can be regarded as the money ratio of different countries, while $A=1$ denotes that the cost unit is Yuan. After analysis, we set:

$$X = 1 - f_i$$

$$Y = \frac{R_i - R_{i.\min}}{R_{i.\max} - R_i}$$

This formula is completely consistent with the model in Ref. [17,18].

Then, the relation between C_i and R_i satisfies the following cost-reliability model:

$$C_i(R_i; f_i, R_{i.\min}, R_{i.\max}) = Ae^{(1-f_i)\frac{R_i - R_{i.\min}}{R_{i.\max} - R_i}} \tag{2}$$

Make deviation analysis with the empirical data of Table 1 and the cost estimate C'_i of Eq. (2), the result is:

$$S = \sum_{i=1}^{4} |C_i - C'_i|^2 = 0.102$$

The factors influencing C_i consist of the module reliability, the feasibility of improving the module's reliability, the initial reliability of module i, the maximum reliability of module i, and so on.

This formula shows that C_i is a monotonically increasing function of R_i, the higher the module reliability is, the higher its development cost is. C_i decreases while f_i increases, because the module with bigger f_i improves its reliability more easily, and the relevant expense is lower. The concrete relation between C_i and R_i while f_i

$=0.1$, $R_{i.\min}=0.7$, $R_{i.\max}=0.99$ is shown in Fig. 1.

How to confirm parameter f_i while using Eq. (2)? Caused by the technical restrictions and the quality of design, the feasibility of feasibility of improving module's reliability in actual projects. Empirical datum benefits a lot while estimating this parameter. Besides, allocate distinguish weights to relevant factors to quantify the "feasible" parameter, is also considered as an important method to estimate this parameter. Except the reliability improvement complexity of module i, the factors relative to f_i include operation section of the module, key degree in the system of the module and so on.

What about the maximum reliability $R_{i.\min}$? When there is no basis, we can think that the maximum reliability of a module is 100%, but this is impossible in actual engineering. Restrictions on techniques and funds have caused the maximum reliability of the module less than 100%. Because the initial reliability of the module has been confirmed, once the maximum reliability is confirmed, the span block of the module reliability will be confirmed. From the relationship between the development cost of module i and the reliability of module i shown in Fig. 1, it can be found that in this span block, development cost of the first half increases very slowly, while the development cost of the latter half especially next to the maximum reliability increases rather rapidly, and reaches infinity greatly in the maximum reliability. Under the condition that the other factors are all the same, to get same reliability improvement, the module whose reliability is more than $R_{i.\max}$ needs less development cost than that whose reliability is less than $R_{i.\max}$. Hence, $R_{i.\max}$ is one of the factors that influence the software development cost. Fig. 1 is presented to illustrate how the maximum reliability influences the software development cost.

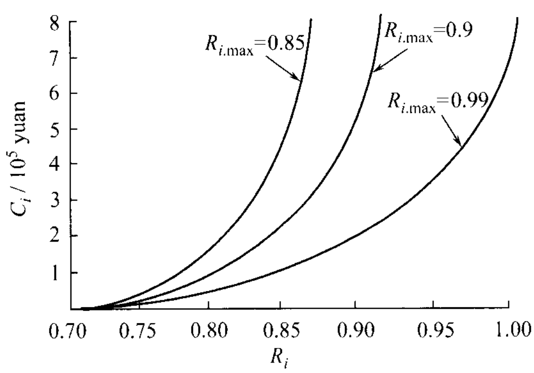

Fig. 1 Relation between C_i and R_i ($f_i=0.01$)

It shows that, when the initial reliability of the module and the value of f_i are all the same, the module with larger maximum reliability has more space to improve its reliability; while in the same reliability block, its development cost is less than the other modules.

Figure 1 shows the general relationship of C_i and R_i. While estimating the relation of C_i and R_i in a certain system, we should adopt a unified cost estimate function. Since different functions have different emphasis, the results will lack of comparability because of different estimation standards.

2 Example Analysis

Apply our empirical data into Eq. (2) and get the following results in Table 2.

Table 2 Application results of empirical model

f_i	R_i	$R_{i.\min}$	$R_{i.\max}$	C_i
0.9	0.8	0.9	0.950 0	1.135 6
0.5	0.8	0.9	0.965 0	1.353 8
0.3	0.8	0.9	0.995 0	1.431 6
0.1	0.8	0.9	0.999 5	1.569 8
0.1	0.8	0.9	0.965 0	1.725 0
0.1	0.8	0.9	0.995 0	1.586 0
0.1	0.8	0.9	0.999 5	1.569 0

After comparison with actual data, the computation results are close to the actual data. It indicates that our empirical formula is of high estimate accuracy.

3 Conclusion

Software reliability allocation is an important procedure of software products design and software reliability design. It tightly relates to software reliability modeling and prediction, the prediction precision of software reliability model [10,14] influences the quality of the final reliability allocation solution directly.

The reliability allocation model presented in this paper minimizes the system development cost, as well as guarantees the software system reliability can achieve the goal. Not only can to simple systems, this model can also be applied to complex systems, determining on the parameters confirmation of this model at first. As to how to confirm the parameters, it still needs further exploration.

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