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Risk-based project value – the definition and applications to decision making

Tomoichi Sato*

JGC Corporation, 2-3-1 Minato Mirai, Yokohama 220-6001 Japan

Abstract

Decision making is a core function of the project management required in planning and execution phases. Decisions shall be made on two or more alternatives, such as 'go or no-go', based on forecasted values of the project status. Conventional project evaluation techniques like DCF method have, however, provided only static evaluation metrics applicable in planning phase.
In this paper, a metrics called 'risk-based project value' (RPV) is presented as the dynamic evaluation of projects. RPV is defined as a summation of realized cash flows and expected cash flows which are discounted by risk probabilities in the future. It can be calculated based on expenses, incomes and the risk probabilities associated with project activities with any given activity network diagram. RPV normally increases as the project progresses toward the goal. Because of this nature, RPV of an entire project can be broken down to each activity's contributed value (CV). The CV of an activity is defined as the increase of RPV after its successful completion.
Analysis with the theoretical framework of RPV and CV provides various application areas of decision such as: (1) go or no-go decision, (2) analysis of risk probability on a project value, (3) risk-based progress control, and (4) budget optimization.

Keywords: project evaluation; risk; value contribution; activity network, budget optimization

1. Introduction: decision problems in projects

Decision making is a core function of the project and program management. Typical example at the program level is 'go or no-go' decision on projects, and sourcing selection and budget allocation are important decisions at

* Corresponding author. Tel.: +81-45-682-8083; fax: +81-45-682-8852.
E-mail address: sato.tomoichi@jgc.co,jp

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the project level. Decisions are generally made based on evaluation of alternatives. Evaluation criteria usually cover economic and non-economic perspectives. If one alternative is apparently superior from all the aspects, there is no need of decision arguments. Decision making becomes necessary when risks/uncertainty resides in consequences of alternatives. There is a strong need for project evaluation method that can adequately cope with risks.

This paper presents a general review of a new metrics called 'risk-based project value' (RPV) and its associated theoretical framework proposed by Sato (2009a, 2009b, 2010, 2013, Sato & Hirao 2012). It can provide methods for quantitative evaluation of the project with risks from economic aspects. It assists managers in decision making in various situations. In this paper at first, we illustrate four typical questions regarding project planning decisions using a simple case. Next, we define RPV and demonstrate how it solves the questions. In consecutive sections we explain applications of the RPV analysis framework. Nomenclatures used in equations are shown as below:

Nomenclature

i, j, k	Activity number indicators
C_i, S_i	Expense at the beginning and income at the end of activity number *i*
r_i	Critical risk probability (probability of project termination) of activity number *i*
RPV_i	Risk-based project value at the beginning of activity number *i*
CV_i	Contributed value of activity number *i*
H_i	Expected future value of descendant activities of activity number *i*
$E\{*\}$	Expected value
W_t, W_s	Penalty rate for time or scope constraint violation

1.1. The four typical decision questions

Let us illustrate typical questions on project evaluation using a simple case. Suppose a new product development project, called "Project Z", is planned by a garage company of two people, an engineer and a salesperson. Project Z consists of two activities A (development) and B (sales), as shown in Fig. 1. The engineer estimates \$20 amount of money is initially required for parts and materials of a new product. He estimates success probability is 50%, since this is the first trial. The salesperson is 90% sure that he will be able to find a customer who buys the product at \$100. Cost for Activity B is considered as negligible. Activity A has a 50% risk probability of failure, and activity B has a 10% risk.

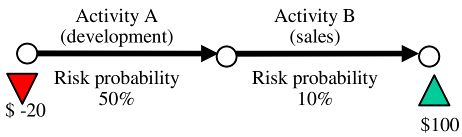


Fig. 1. Project Z. (adapted from Sato, 2009a)

Now, four questions may come up to their mind regarding Project Z:

(Q1) What is the value of this Project Z? If someone offers to acquire their idea at a price of \$35, should they agree to sell it?

(Q2) What are contributions by the two activities to Project Z? In other words, what is the fair share between these two people when this project achieves its goal?

(Q3) What is the progress percentage after activity A (development) is successfully completes?

(Q4) Are there any measures to increase value of Project Z at this moment of planning?

Although various project evaluation methods have been proposed and used in practice to date, none of them can provide direct answers to these four questions in a consistent manner.

1.2. A brief review of project evaluation methods used today

The discounted cash flow (DCF) method and its criterion Net Present Value (NPV) is most commonly applied to investment project evaluations in financial sectors (Remera, et. al. 1993). It is based on a concept known as “the time value of money”. NPV is a summation of future cash flows discounted by the cut-off rate (COR). Internal rate of return (IRR) is defined as the COR at which NPV becomes zero.

The DCF method can answer Q1, as far as the duration of Project Z and a COR are given. It is recommended to determine COR from a weighted average cost of capital (WACC) plus risk premium. WACC depends on the capital structure of a company, not on a specific project.

The DCF method has three weaknesses. First, it disregards the concept of WBS of a project, although yearly cash flows are evaluated. Since it provides no tools to weigh importance of activities, it does not allow us to solve Q2 or Q3. Second weakness is that NPV is just a static evaluation applied once in project selection phase. It lacks sense of value development or progress made by a project. DCF method cannot support our decisions when we encounter situations that we have to compare an ongoing project to a new planned project. Third limitation of the DCF method is that NPV does not include the aspect of project specific uncertainty.

Real option analysis (ROA) is developed to overcome some weak points of DCF (Copeland & Antikarov, 2001). ROA is conducted to capital investment projects based on the decision tree which shows payoffs of the asset at each node. ROA evaluates the flexibility of management decisions by regarding a project as a volatile asset. It assumes the project volatility is basically driven by external factors such as market prices. However, Project Z may be forced to termination by its internal risks. ROA can evaluate the stop option only if there are ways to sell off the failed project at a certain price. ROA cannot directly answer Q2, Q3 or Q4.

The Earned Value Management System (EVMS) is a technique widely used by project management practitioners. EVMS regards budgeted cost of work performed as ‘earned value’ (EV) by the activity. Despite its name, EVMS does not take into account the income values. It is essentially a cost/progress control tool. According to EVMS, answer to Q3 becomes 100%, since cost for Activity B is negligible. It does not answer Q1, Q2 or Q4.

Clearly, a new theoretical framework is needed that can respond to the above four questions in an integrated manner. It must have capability to evaluate a project with its activity structure. It should be able to take into account the cash flows and quantified specific risks associated with the comprising activities. It has to be a dynamic evaluation method applicable at any moment of a project life cycle. The risk-based project value (RPV) is a metrics that satisfies these requirements.

1.3. Definition of risk-based project value (RPV)

Let us illustrate concept of the RPV using the case of Project Z.

The probability of overall success of the project is (100 – 50)% x (100 – 10)% = 45%.

Expected value of income is \$100 x 45% = \$45 at the beginning of activity A. Therefore, the project value is \$45 – \$20 = \$25, based on its risk probabilities.

When activity A is successfully completed, the expected income becomes \$100 x 90% = \$90. Therefore, project value increases to \$90 – \$20 = \$70. When activity B is also successfully completed, project value is realized as \$100 – \$20 = \$80. These values, \$25, \$70, and \$80, are RPV at the start of the project, beginning of activity B, and at the project completion, respectively. This gives the answer to the above Q1 about the project value. On the planning stage, value of Project Z is only \$25 and less than the acquisition offer at \$35.

The value of each activity is defined as an increase of RPV. For this case, the contributed value (CV) of activity A is \$45, while activity B is only \$10 as shown in Fig. 2. Therefore, answer to Q2, fair share between the two people, is 45:10 accordingly.

It should be noted that value contributed by an activity will be positive, even if the activity itself does not obtain income *S*. It has value because its completion reduces risk and enhances RPV. Although activity A merely consumes cost (= cost center function) and B earns money (= profit center function), contribution of A is much greater than that of B. This is because activity A is more difficult. Its success greatly increases project expectations.

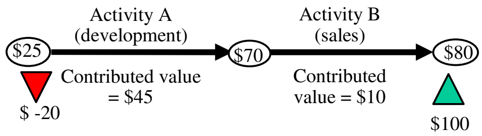


Fig. 2. Risk-based value of Project Z. (adapted from Sato, 2009a)

Q3 about progress percentage at the completion of activity A can be defined using values of the two activities. Total values to be achieved by activity A and B are \$45 + \$10 = \$55. At the middle point, activity A has contributed by \$45, which means progress is made by 45/55 = 81.8%.

How can we answer Q4, measures to improve the value of Project Z when we do not even have any knowledge about the product? Suppose they invest \$40, instead of \$20, to allow the engineer two manufacturing trials in parallel. If either one trial successes, the salesperson can sell it (see Fig. 2').

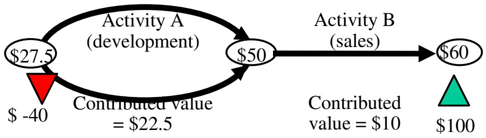


Fig. 2'. Risk-based value of Project Z.

Risk probability of activity A failure is now reduced to 50% x 50% = 25%. Because they pay \$40 up front, RPV at the final point will be \$100 – \$40 = \$60. At the middle point, expected income will be \$90 and RPV will be \$90 – \$40 = \$50. However, RPV at the initial point is \$90 x (100% – 25%) – \$40 = \$27.5. It is greater than the original plan \$25. Contributed value of activity A is now reduced to \$22.5, while that of B is unchanged.

This type of risk aversion approach is called 'parallel funding strategy' and often put in practice in R&D project areas (Bard 1985, Boyer 1999). With the parallel funding strategy we can enhance RPV even if we do not know technical details of the project.

2. Formal definitions of RPV and CV

In this section we introduce formal definitions and calculation methods of the RPV and CV. We start with a simple model and then extend it to more complex ones in the consecutive sections.

2.1. Premises of analysis

The RPV analysis shall be conducted after an appropriate project planning is done in accordance with the well accepted best practices such as defined by Smith &Meritt (2002) or PMI (2012). It is assumed that WBS and an activity network are properly developed, costs and schedules are estimated, and risk probabilities are assessed.

Projects are assumed to bear monetary incomes which are primary criteria of their success. Although decision making shall be a comprehensive process based on various aspects including intangible benefits, cash flow values play most important roles. The RPV analysis focuses on tangible values of project.

2.2. RPV and CV for simple and phased projects

We start with definition of the RPV for a 'simple' type of project which is comprised of a single activity (see Fig. 3). Initial cost C is spent upfront and income S will be gained after its successful completion. There is risk probability r for unsuccessful termination during execution. RPV of this type of project is defined as follows.

Before starting the project: $\mathrm{RPV} = (1 - r)S - C$ (1)

After completion of the project: RPV = $S - C$ (2)

Successful completion of the activity increases RPV by (1) – (2) = rS. This is CV of the activity, which is proportional to r. It means the more the activity is difficult to achieve, the greater the contributed value becomes.

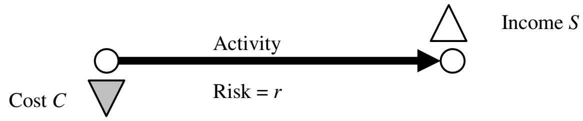


Fig. 3. RPV for 'simple' type of project. (adapted from Sato & Hirao, 2012)

Next, we examine 'phased' type of projects that consist of series of activity starting 1 to N. C_i, S_i and r_i are initial expense, final income, and risk probability of activity number i, respectively. Risk probability of each activity is assumed to be independent from other activity. S_i for early activity in a project is often zero in real cases.

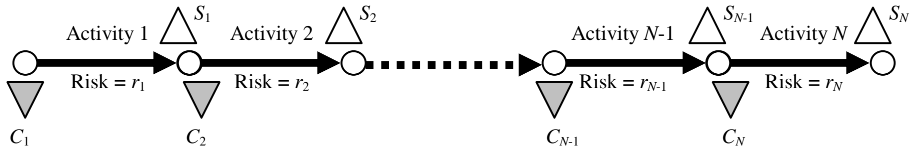


Fig. 4. RPV for 'phased' type of project. (adapted from Sato & Hirao, 2012)

$$RPV_i = \sum_{k=1}^{i-1}(S_k - C_k) + \left[(1-r_i)(S_i + H_i) - C_i\right] \quad (3)$$

$$Where \;\; H_i = \sum_{k=i+1}^{N}\left[S_k \prod_{j=i+1}^{k}(1-r_j) - C_k \prod_{j=i+1}^{k-1}(1-r_j)\right] \;\; and \;\; r_0 = 1.$$

The first term on the right hand side of Eq. (3) is cash flows realized by the time. The second term is cash flows to be achieved by the current and future activities. H_i represents the expected future cash flows after activity i, which is discounted by future risk probabilities. Eq. (3) satisfies even if $S_i = 0$.

The contributed value CV of activity i is defined as the increase of RPV after the activity.

$$CV_i = RPV_{i+1} - RPV_i \quad (4)$$

The CV of the final activity N is defined as the difference between RPV_N and the total cash flow achieved after all the activities successfully completed:

$$CV_N = \sum_{k=1}^{N}(S_k - C_k) - RPV_N \quad (5)$$

From Eq. (3) and (5), the following relationship is derived. Activity's CV for the phased type of projects is also proportional to its risk probability.

$$CV_i = r_i(S_i + H_i) \quad (6)$$

There is also 'complex' type of projects that has multiple parallel and serial activities in their network diagrams. As to the calculation method for complex type, please refer to Sato (2009b).

2.3. Relationship between RPV and NPV of DCF method

Suppose we apply the DCF method to evaluate NPV of the simple type project using R as the discount rate for "future" income S and C as "present" investment, then NPV is:

$$NPV = \frac{S}{1+R} - C \tag{7}$$

From the viewpoint of capital gain, the investor would determine interest rate R to investment C so that its expected return is greater than loss through failure. If the project is successful, the investor will obtain RC at a probability of $1–r$. If it fails, the investor will lose C at a probability of r. The necessary condition is as follows:

$$(1-r)RC - rC \geq 0\,, \quad \therefore R \geq \frac{r}{1-r} \tag{8}$$

Eq. (7) can be rewritten with using condition (8) as:

$$NPV = \frac{S}{1+R} - C \leq (1-r)S - C \tag{9}$$

R is determined solely by r, regardless of C or S. Eq. (9) is a theoretical reasoning of the cut-off rate R used in the DCF method. (Note: If we consider the investor's capital cost at risk-free interest rate r_f, then the numerator of Eq. (9) will become $r + T r_f$, where T is project duration. In this paper, however, capital cost term is neglected for the purpose of simplifying the equations. The conclusion reached is unchanged even if r_f is considered.)

In the case of a phased type of project, RPV_1 equals NPV of the DCF method, when it is assumed that r_i for all activities is identical and the cut-off rate R is given by Eq. (9). As we discussed in section 1, such is not a practical assumption. Approach with the RPV is a generalized method covering the classical NPV in the DCF.

3. Extension of the RPV analysis framework

3.1. RPV for projects with reworks

RPV analysis in previous sections has dealt with critical risks only. The critical risk is a possibility of activity failure that will lead the project to termination. There are other types of risks, however, just affecting project performances, such as total income, total cost, deliverable's quality, and spent time. In this section, we will extend the analysis framework so that other types of risks can be taken into consideration.

First, we examine RPV with possible reworks. Rework (recycle work) of a failed activity is one way to avoid critical risks wherever the project manager considers it possible. Let us suppose a project consisting of a single activity which, in case of failure, can start over from the initial point (see Figure 5).

If number of trials is allowed up to N times, then overall risk probability becomes r^N. Keeping in mind that an original RPV_0 is $(1 – r)S – C$ without reworks, RPV and average cost $E\{C\}$ with reworks become as follows.

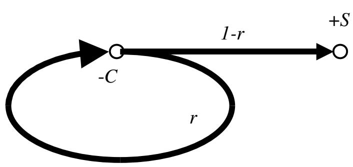


Fig. 5. Project Network Diagram with Possible Reworks. (adapted from Sato, 2010)

$$RPV = (1 + r + r^2 + \ldots + r^{N-1})RPV_0 = \frac{1 - r^N}{1 - r} RPV_0 \qquad (10)$$

$$E\{C\} = \frac{1 - r^N}{1 - r} C \qquad (11)$$

If number of rework N is unlimited, then the average cost is:

$$E\{C\} = \frac{1}{1 - r} C \qquad (11')$$

3.2. RPV for performance risks

Next, we examine more common: cost overrun and income decrease risks. Use of untrained resources is a typical example that may end up with more costs and less incomes. Although these risks may not necessarily lead to project cancelation, they impair project's economic performances. We call them 'performance risks'.

Suppose the cost C is a stochastic value instead of deterministic value. Cost depends on a probability density function $p_c(C)$, and it does not fall below a certain minimum cost $C_{\min}$. We define metrics r_c for the cost overrun risk of an activity with expected value of cost $E\{C\}$.

$$r_c = 1 - \frac{C_{\min}}{E\{C\}} = 1 - \frac{C_{\min}}{\int_{C_{\min}}^{\infty} Cp_c(C)dC} \quad \text{or} \quad E\{C\} = \frac{C_{\min}}{1 - r_c} \qquad (12)$$

For instance, when an activity's minimum cost $C_{\min}$ is estimated as 800 and r_c =0.2, its average cost C is 1,000. If an activity's average cost always becomes 2 times of its minimum estimate, then r_c =0.5. Please note that r_c is within a range from 0 to 1. Eq. (11') representing the cost with rework becomes identical to Eq. (12), if maximum number of rework N is limitless. In other words, r_c is closely related to risk probability r with reworks.

Similarly, we introduce a probability density function p_s (S) for activity's income S. S cannot exceed a certain maximum income value $S_{\max}$. We define risk probability r_s for income decrease of an activity.

$$E\{S\} = \int_0^{S_{\max}} Sp_s(S)dS = (1 - r_s)S_{\max} \quad \text{or} \quad r_s = \frac{1 - E\{S\}}{S_{\max}} \qquad (13)$$

The definitions of RPV in Eq. (3) and CV in Eq. (6) are extended to include these three factors: r, r_c and r_s.

$$RPV_i = (1 - r_i)H_i + (1 - r_{s,i})S_{i\max} - \frac{C_{i\min}}{1 - r_{c,i}} + \sum_{k=1}^{i-1}(S_i - C_i) \qquad (14)$$

$$CV_i = r_i H_{i\max} + r_{si} S_{i\max} + \frac{r_{ci}}{1 - r_{ci}} C_{i\min} \qquad (15)$$

3.3. RPV for reworkable risks with time or scope constraints

Projects are often constrained by delivery date or scope of work. These constraints are either soft (with penalty payments) or hard (non-breakable). Infringement of hard constraints leads a project to termination. We can evaluate negative impacts of the time and scope risks on RPV, when their causes are considered reworkable. If activity i is associated with reworkable risk probability r_i under a soft time constraint with delay penalty, then RPV shall be deducted by $r_i[C_i + W_t \text{ Max}(0, T_i - TF_i)]$, where W_t is penalty rate on project delays, T_i is duration of activity i and TF_i as its total float. If the final date is a hard constraint, then the project has to complete with a reduced scope. Impact on RPV shall be $-r_iW_sS$, as future project revenue S will be reduced in proportion to the uncovered scope with the risk r_i and penalty rate W_s. In case the time and scope are both hard constraints, then the project team cannot do rework and has to terminate. Impact is $-r_iS$, the same as in case of the critical risks. Please note that impacts to RPV are proportional to r_i with constant values for all cases.

3.4. Risk-based Progress Measurement and EVMS

Conventional progress measurement of EVMS is based on budgeted costs of activities (Anbari 2003). Concept of Risk-based progress measurement was proposed by Sato (2010) using the activity's CV as its weight factor. It is defined as a ratio of earned value to the overall value and has higher sensitivity to early activities with higher risks than the cost-based method (see also section 4). The term $\{m\}$ in the following equations represents set of activities accomplished by the time of measurement.

$$\frac{EV}{Total\ Value} = \frac{EV}{\sum_{i=1}^{N}(S_i - C_i) - RPV_1} \text{ ,where } EV = \sum_{i\in\{m\}} CV_i = \sum_{i\in\{m\}}\left(r_i H_{i\max} + r_{si} S_{i\max} + \frac{r_c}{1-r_c} C_{i\min} \right) \quad (16)$$

Activities in investment phase do not usually have incomes (S_i). In addition, if activity reworks are allowed, termination risks (r_i) can also be neglected as we discussed in section 4.1. Therefore, only the third term is dominant in many cases. If we suppose all activities' cost overrun risk r_c are equally 0.5, then EV becomes,

$$EV = \sum_{i\in\{m\}} CV_i = \sum_{i\in\{m\}}\left(\frac{0.5}{1-0.5} C_{i\min} \right) = \sum_{i\in\{m\}} C_{i\min} \quad (17)$$

Eq. (17) is the same as the conventional progress measurement in EVMS. It means the cost-based measurement can be derived as a special case from the RPV analysis framework, with an assumption of r_c=0.5.

4. Case study - new product development project and risk-based progress

Let us demonstrate RPV analysis on a new drug development project and show how it can be applied in the pharmaceutical industry which is characterized with large costs and high risks.

A drug development project can be regarded as 'phased' type consisting of five activities. Table 1 shows summary of a model project 'Y'. Cost and risk figures are assumed based on the industry statistics and in-depth research by Kuwabara (2006). After Project 'Y' completes, production and sales operations will continue. We assume revenues as 300 billion Yens and production costs as 30 billion Yens for the entire life cycle of the drug.

Table 1. Costs and risks of a drug development project 'Y'.

Activity	Cost (in 10^6 Yen)	Risk probability of termination (r)
Pre-clinical test	500	50%
Phase-1 test	200	30%
Phase-2 test	1,000	60%
Phase-3 test	5,000	30%
Government approval	100	10%

RPV and CV at the beginning of each activity are calculated as in Fig. 6a. Following results are derived from the calculation (costs are all in billion Yens).

(1) RPV at the starting point of Project 'Y' = 20.8.

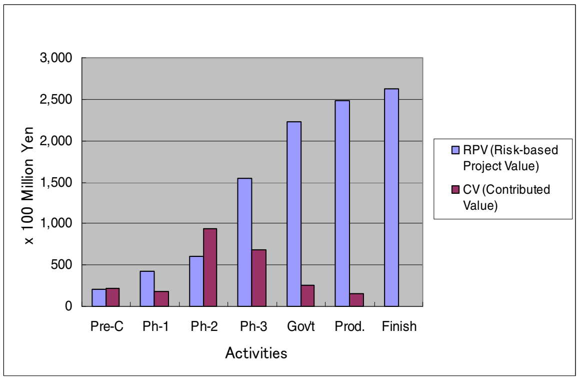
(2) RPV at the finishing point of Project 'Y' = 263.2.

(3) Total of CVs of the entire Project ‘Y’ = 263.2 – 20.8 = 242.4.

(4) The maximum of CV is of the Phase-2 activity (93.3).

Kuwabara (2006) argued Phase-2 test is the most critical in the new drug development and it is most efficient to make ‘go/stop’ decisions during Phase-2. Our finding (4) proves the importance of Phase-2, backing his research.

Fig. 6b shows comparison of the two progress evaluation methods; cost-based and risk-based calculation. The cost-based measurement weighs only 25.0% even after Phase-2 test, because the majority of costs are borne by Phase-3 activity. Risk-based progress is 58.5%, which matches project manager’s insights better.



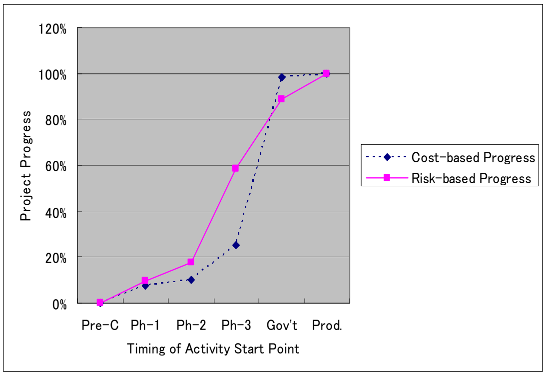


Fig. 6a. RPV for new drug development project ‘Y’. (Sato 2010), Fig. 6b. RPV vs. Budget of Phase-2.

5. Discussions

5.1. Relationships with DCF and EVMS

Up to now, DCF method and EVMS are two different techniques developed from independent backgrounds. RPV analysis has revealed that both NPV and EV can be derived for the phased type of project with special assumptions. NPV equals to RPV when critical risks and durations are identical for all the activities. Progress measurement based on EV becomes identical to the measurement based on the CV when cost overrun risks are 0.5 for all the activities. RPV analysis is thus proved to be a more general and integrated framework which includes NPV and EV as special cases.

5.2. Assessment of risk probability

Results of RPV analysis mainly rely on estimation of the risk probability r, since the other consequences are mathematically derived from it. Its estimation process shall be based on identification of risk drivers and combination of its probabilities. For instance, suppose an air transportation project is analysed, and critical incident is driven either by mechanical troubles, stark weather conditions or pilot’s miss-operation. Critical risk is calculated as the probability of occurrence of either one of them. If the risk drivers’ probabilities are 2%, 10% and 5% respectively, then r is $1 – (1 – 0.02)(1 – 0.1)(1 – 0.05) = 0.162$.

Although activities may be different with each project, common risk drivers are often identified and quantified. Taking design activity as an example, its purpose and work volume may vary each time. However, probability of human error per thousand man-hours could be applied as one of common risk driver. Past records of similar experience and industry statistics can help such estimations (Ericson 1999, Danzon et al. 2005). Hearing with project management experts and heuristic judgment based on their experiences are also valuable. Eq. (11) and (12) also enable to estimate risk probability r of an activity from statistics on past cost overrun and/or rework records.

In case no similar experiences are available, the subjective probability shall be applied with appropriate Bayesian inference methodology (Matsubara 2001).

5.3. Other Applications of the RPV Analysis

RPV analysis can support various decisions in program and project management, such as project selection. When we select a project from a mutually exclusive list, the one having the highest RPV shall be chosen. When selecting from a list of mutually independent projects, then priority shall be given in order by ratio of RPV to project cost. If RPV of a project is negative, it should not be launched in either case.

Go/stop decision of ongoing projects is another application area. For this purpose, ratio of H_i/Cost ETC (=estimate to complete) shall be used as evaluation criteria. H_i represents a future cash flow discounted by future risks of the ongoing project as in Eq. (3) and (14). This ratio is risk-based version of DIPP, a metrics proposed by Devaux (1999) for project portfolio management. It usually increases as a project reaches closer to its goal.

We saw the parallel funding strategy could improve RPV in Project Z in Section 1.3. RPV analysis can derive existence of the optimum budget allocation for any project that maximizes its RPV, when we assume a mathematical model between activity's budget and risk probability using the generalized parallel funding strategy. It solves the trade-off problem between proactive risk aversion and budget increase. Please refer to Sato & Hirao (2012) for further details.

6. Conclusion

In this paper, the theoretical framework of RPV analysis is presented. RPV is a dynamic evaluation of a project and defined as a summation of realized cash flows and expected cash flows discounted by risks in the future. It can be calculated for any activity network diagram. RPV can incorporate with various types of risks.

Development and validation of this method is desired with more practical cases. In the project management area it is difficult to have repeated experiments in the scientific sense, however. We would conduct validation processes using backward application of RPV analysis to management decisions in past case studies in R&D, engineering or resource development project areas. Evidences would be accumulated through comparison of theoretical results with actual decisions.

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