Industrial Paper

Quantitative Risk Management Method using Logistic Regression Analysis

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Abstract -

Recently, the interest in the risk management (RM) process has been growing. RM aims to lead a project to success by eliminating negative factors that can cause it to fail. Therefore, it is expected that the number of failed projects can be reduced in organizations where have introduced RM process. However, this expected result has not been obtained yet. In this study, we first analyze the RM process for the system development projects conducted recently, then we figure out that the issue is that the RM implementation is not in time for actual trigger where RM process introduced successfully. Next, we identify the factors where RM did not meet the expected criteria and propose a quantitative RM method that could improve the RM and project management (PM) process by using Earned Value Management (EVM) and Logistic Regression Analysis (LRA) to eliminate the factors. By applying the proposed method to a real RM case, we concluded that the proposed method is effective.

Keywords: Project Risk Management, Logistic Regression Analysis, Quantitative Project Management

1 INTRODUCTION

We live in a software dependent society in which software plays a major role in various kinds of products such as organizational operation systems, home appliances and automobiles. It means that many companies inevitably focus on system development including a large amount of software.

However, according to reliable statistical information[1], only 27% of projects succeed in all aspects of quality, cost, and delivery time (QCD) in domestic and foreign system development projects. Thus, three-fourths of the projects do not meet all the QCD criteria, which leads to the cancellation of 24% of software development projects[2].

To solve this problem, interest in introducing RM processes in system development has increased. It is believed that RM has the ability to lead projects to success by eliminating negative factors that may cause the project to fail.

To introduce RM processes, an international "best practice model" has adopted the Project Management Body of Knowledge (PMBOK)[3], Program & Project Management for Enterprise Innovation (P2M) [4], the 2nd version of Projects in Controlled Environments (PRINCE2) [5] as reference models, and introduced specific practices for RM that all presented in these guides.

However, even the introduction of the "best practice," does not reduce the number of failed projects. The findings suggest that successful implementation of the RM process does not contribute toward the reduction of failed project occurrence.

We believe that there are two major factors that contribute to the event described above.

One factor is that the project management standards and guides that have been proposed and developed overseas do not match practices that are in place in the domestic system development projects. This is because the standards and guides developed overseas are often based on large-scale projects. For example, the Capability Maturity Model Integration (CMMI) has been developed based on the assumptions drawn from the procurement model of the Department of Defense (DoD) of the United States. The DoD constantly carries out large-scale projects for procurement of munitions. Although it is extremely difficult to apply these assumptions to standard-sized system development projects in Japan, the focus was on the necessity and not on the prevailing practices.

The other factor is that even though the standards and guides are correct, they have not been successfully introduced to the system development site. When standards or guides are introduced to a system development site, conformance to the standards and guides take precedence. However, the goal of these standards and guides is not conformance, but performance.

In both cases, it is necessary to establish an appropriate methodology to introduce RM processes to the management of standard-sized projects in Japanese industry.

To address this issue and decrease the incidence of failed projects, we first analyze four cases of a specific risk management process conducted recently and identify the factors that will create a bottleneck. Next, to solve the problem of failure, we proposed a method to introduce the RM process appropriately. The proposed method included quantitative risk management and the implementation of risk countermeasures. When we applied our proposed method to a real case for the RM of system development projects, a measurable effect was observed in the form of a reduction in the number of failed projects and a reduction in the contingency budget.

The remainder of this paper is organized as follows: In Section 2, we review the related works on PM, EVM and RM to confirm the originality of this study. In Section 3, we analyze a case on the implemented RM practice where we consult and identify the reason behind the failure of RM, and describe the issues to be solved. In Section 4, we propose a quantitative RM method by using a statistical tool LRA. In Section 5, the effectiveness of the proposal is evaluated by applying the method to a real case of system development. In Section 6, we discuss the results of the case study. In Section 7 presents the conclusion.

2 RELATED WORKS

The first step in designing a research strategy involves specifying the research question. The research question is how to establish a new methodology for RM that involves the application of quantitative PM and EVM for performing risk corrective/preventive actions. The second step is to apply this methodology to the real case on RM and evaluate the effectiveness of the proposed method.

Hereafter, we review the prior research in the field of RM, PM, and EVM.

2.1 RM

Project risk is defined as an uncertain event or condition that, if it occurs, would have a negative effect on one or more project objectives such as scope, schedule, cost, or quality [3].

In most of the earlier research on RM of system development, Boehm[6] and Williams[7] initially introduced the implementation methods of RM practices that are commonly practiced, such as risk identification, evaluation, classification, and prioritization. In this methodology, after the establishment of the basic RM basic technique, the researchers attempted to optimize the project schedule by considering the simultaneous effect of the risk associated with one task on the other risks factors; these factors are proposed in a quantitative framework of analysis for supporting decision making in project risk response planning.

They used a design structure matrix representation to capture risk interactions and build a risk propagation model for predicting the global mitigation effects of risk response actions. Unlike the technique proposed by the author, they did not exploit the potential of the methodology for exploring the impact of the risks on a single activity, thereby neglecting how the network topology could change in relation to the risk propagation and determine possible project delays.

Acebes et al. [13] proposed a methodology to integrate EVM with risk management, based on traditional EVM indicators that allow project managers to detect negative deviations from planned values, corresponding to cumulative positive or negative cost/schedule buffers. Such information can be usefully employed to take corrective actions or identify the sources of improvement and further optimize project activities.

Muriana et al. [9] explained a deterministic technique for assessing and preventing project risks, by determining the risk of the work progress status. As each phase ends, the actual value of the input factors are detected and compared with those of the planned values, and corrective actions are taken for considering the impact of the actual performances on the overall project. The current risk degree of the project is determined through the weighted sum method. If it is higher than planned, then preventive actions are taken to mitigate the risk of the entire project. However, the authors limited their work to the determination of the deviations from planned values, without focusing on preventive/corrective actions that can be put into practice.

2.2 PM

The origin of modern PM can be dated between 1900 and the 1950s [8]. Before the 1950s, the focus of PM techniques was primarily on scheduling, that is, the understanding of activities and sequencing. PM is a critical activity that determines the success or failure of a project. Therefore, several techniques have been perfected over time to simplify the efforts related to such an activity and increase its usefulness.

The first attempt to support project managers in the scheduling phase was made with the introduction of the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT); additionally, these methods were invented and introduced in the 1950s. However, CPM posed uncertainties regarding which deterministic techniques allow the determination of the longest path in the network named "critical path" and which tenure is taken as the earliest time for project completion. The PERT was introduced some years later, adding to the hypothesis of uncertainties regarding the activity duration.

After the dawn of this era, a lot of new approaches of PM were proposed and attempted. Some works have focused on communication and coordination issues in projects. Curtis et al. [14] studied how communication networks and breakdowns affected a development project. Their findings raised many issues that are critical for awareness systems, such as the importance of both formal and informal communication in development. Gutwin et al. [15] looked at several open source development projects and found that developers needed to have an awareness of other factors to contribute toward development and that the developers gained an awareness primarily through text based communication. Herbsleb and Grinter [16] conducted a field study showing the importance of informal communication; furthermore, the difficulty in communicating across globally distributed teams suggested that an increase in awareness would benefit development.

Others have looked at the mismatch between coordination requirements and actual communication [17], [18] and proposed mechanisms to improve the mismatches that occur. Espinosa et al. [19] have identified factors that affect awareness in software development, including awareness about the nature of team knowledge and distance.

Finally, a simulation method has proposed a technique to manage project scheduling [10], rapidly becoming one of the most-used techniques for large-sized projects affected by uncertainties emerging from the activities.

2.3 EVM

In 1962, the Work Breakdown Structure (WBS) was invented. In particular, it provides project managers with techniques for monitoring a project through the employment of EVM. EVM was introduced in 2000 in the PMBOK guide and is today broadly employed in the field of PM for measuring project performances [11] because it combines measure-

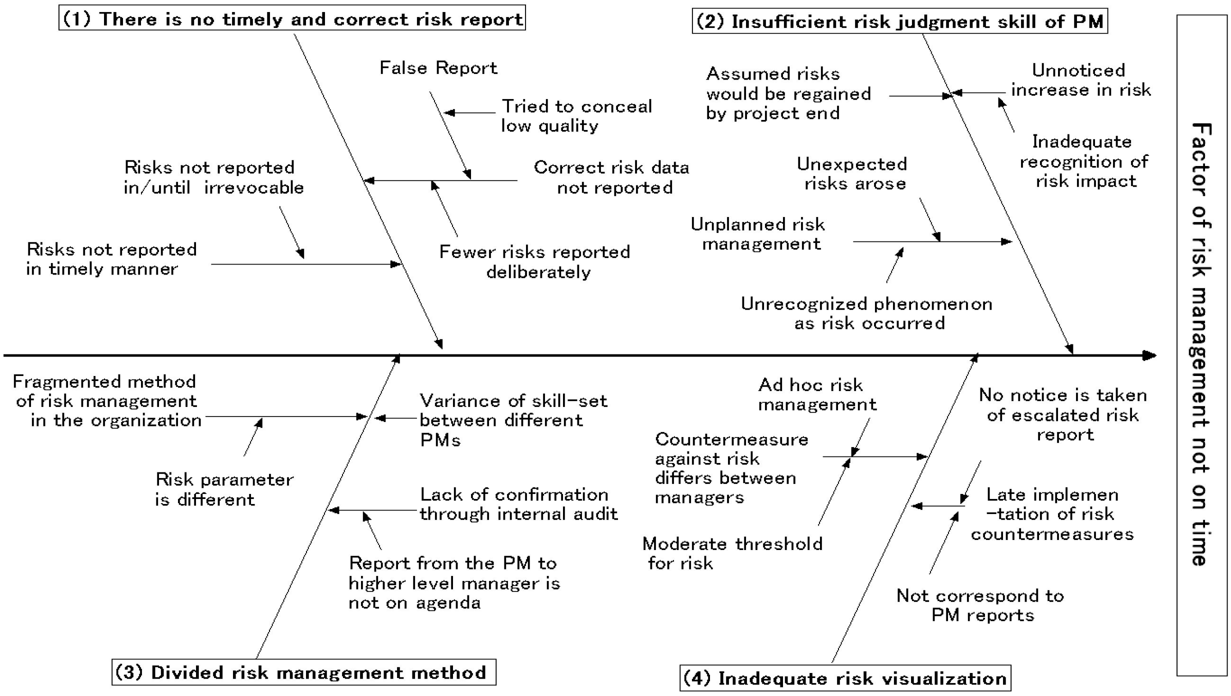

Figure 1: Fish-Bone Chart of Problems.

ments of the Iron Triangle of the PM. The usefulness of EVM in forecasting the project performances is widely recognized, and considerable research has been published that attempts to extend this technique.

The introduction of EVM technique was followed by studies that proposed a method similar to that of quantitative management. For example, Pajares et al.[13] proposed two new metrics that combine the EVM and Project RM for project controlling and monitoring. The study compares the EVM cost and schedule variances with the deviation that the project should have under the expected risk analysis conditions that allow project managers to analyze whether the project overruns are within the expected variability or there are structural and systemic changes over the project life cycle.

Deshpande at el. [21] compared correlation and regression coefficient using three distributions. Function exaction using correct distribution for forecasting project duration and cost will prevent significant losses in future. Therefore, an attempt is made to find the alternative distribution of cost performance index (CPI) and schedule performance index (SPI) for better decision making. If the project schedule performance shows poor results, then it would be essential for a manager to take corrective actions with the help of this tool.

Although such prior research explains the potential of success for the RM, it does not describe how to establish a methodology that can be applied to the system development project in the real world. To the best of our knowledge, no particular prior research discusses the appropriate methodology for introducing the risk management process.

3 FACTORS CONTRIBUTING TO THE FAILURE OF RM

3.1 Case Analysis of RM Process

First, we aim to clarify the reasons due to which the number of failed projects has not decreased, even after best practice of the successful introduction of the RM process in organizations. We analyze the factors by taking up four organizations for whom we have provided management consultation to date. Below is a summary of the organizations to be analyzed:

- Case 1 Electronic control of vehicle amenity
- Case 2 Electronic notebook, which maintains a schedule, dictionary, calculator, and custom program
- Case 3 Air conditioner system controlled by an internet-based remote control
- Case 4 Derivative development of value-added of acoustic measurement calibration equipment

By analyzing the 4 aforementioned development cases, we found the following four problems in the RM process:

- Problem 1 Since the triggering of alarm for the notification of risk was delayed by the project manager (PM), risk countermeasures could not be implemented on time. A similar problem occurred multiple times in a PM's tenure; he thought that the problem could be solved every time. Therefore, he did not report the emergence of risk to the higher-level managers.
- Problem 2 Since the development project was originally planned the development period, it was biased toward keeping the delivery date. Therefore, the organizations

Project Management PDCA

	Plan	Do	Check	Act
Project Manager	Making Risk Management Ledger and WBS		Risk Analysis using LRA	Activate Risk Counter Measure
Development		WBS update weekly RM Ledger update process breaks point		
Risk Management	PV=EV	As always EAC/BAC > 100 %	If Recoverable % > (EAC/BAC -100%)	Drive Recoverable % < (EAC/BAC -100%)

Figure 2: Procedure of this proposal.

were averse toward reworking due to RM activities and hence hesitated to report risk occurrence.

Problem 3 Despite the original plan to activate risk response measures in an event-driven manner, project members did not accurately understand the RM process and subsequently reported risks at weekly progress meetings that caused notification delays.

Problem 4 Despite a clear definition of the trigger and threshold for risk interpretation in the RM ledger, the roles and responsibilities were misunderstood, and the risks were not reported correctly.

The four problems listed above indicated that the RM practice was correct, but that risk countermeasure actions were not implemented on time.

3.2 Factor Analysis to show that RM was not Implemented on Time

Next, we analyze factors that contributed toward the delayed occurrence of RM by creating a fish-bone diagram, as shown in Figure 1, extracted from the documents and minutes of the meeting of the past RM assessment. As a result, the following four factors were clarified:

Factor 1 There was no timely and correct presentation of a risk report:
Even when the risks expanded and severe delays did not allow adequate management, organizations sometimes reported less risk or kept critical risks hidden since the project was at a stage wherein it would be evaluated by higher-level managers. Therefore, a correct risk report was not delivered on time. This is the cause of Problem 1.

Factor 2 Insufficient risk judgment skill of the PM:
Due to the PM's insufficient risk judgment skill, such as insufficient identification of risk and undistinguished critical risk, the organization failed to manage the risk properly. This led to Problems 1, 3, and 4.

Factor 3 Divided RM method:
Due to insufficient communication between the PM and higher-level managers, unclear terms and methods were used, and insufficient information was presented, which contributed to Problems 2 and 3.

Factor 4 Inadequate risk visualization:
The RM ledger included the PM's subjective evaluations. Higher-level managers were unable to monitor risk situations of the projects, which contributed to the Problem 4.

4 RM METHOD USING QUANTITATIVE PROCESS MANAGEMENT

4.1 Basic policy

A risk is a potentiality thing, and it does not necessarily become explicit. Therefore, the activation of risk countermeasures ahead of schedule will lead to the employment of unnecessary labor and costs.

For establishing a good RM process, it is important to define the risk of each project and judge them objectively by using quantitative data.

(1) Set a clear risk criterion
Objective judgment criteria are set for practicing each RM process, such as registering in the RM ledger, identifying risk explicitly, and using the quantification method.

(2) Process Performance Baseline (PPB)
With an emphasis on historical project data, not focusing on each project database, but the PPB focus on all historical projects' data accumulated.

(3) Evaluating the entire project status using a statistical method
The individual risk threshold is not evaluated, but whole project threshold is evaluated using a statistical method.

(4) Introduction of subject matter expert (SME) and quality assurance (QA): To solve the problem of skill shortage related to RM, an SME, a specialist of the development

No	Risk Description	Probability	Impact	Rework	Response	Threshold	Countermeasure	Priority
1	Delivery from outsourcing companies tends to be delayed	H	H	100	Mitigate	May 11th	add resource	3
2	The quality of some project member 's program is always bad	M	H	100	Mitigate	Design Process	assign mentor	4
3	Influenza will become prevalent and absentees will appear	L	L	300	Mitigate	RA Days	Reserve party	1
4	The president may change and the policy may change	L	M	200	Mitigate	Gen meeting of shareholders	New Strategy	2
	H:High, M:Middle, L:Low		Total	700				

Figure 3: RM Ledger.

process who belongs to the engineering field, and a QA are introduced to discuss risks activities.

(5) Alignment Aligning the basic policies of (1) to (4) with the RM process.

4.2 Procedure

In order to solve the issue concerning a delay in the RM, which was identified in section 3.2, we will introduce the following RM procedures: making RM ledger and WBS, quantitative progress management using EVM, risk analysis using LRA, and risk counter strategy. These RM Procedures are shown in Figure 2. Hereafter, we will explain the RM procedures in detail.

4.2.1 Making RM Ledger and WBS

In Stage 1, we first make RM ledger and WBS. In the system development project, risks of the entire project are identified at the project planning stage. Mainly, risks are obtained as a result of awareness created during the process of analyzing customer need, creating customer requirement definition, creating project planning, and reviewing the QA Document.

The obtained risks are listed in the RM ledger of the project, and the properties of each risk are set as shown in Figure 3. These properties include risk description, probability, impact, rework time, risk response strategy, the threshold of action taken, risk countermeasures, and priority. Priority is that the magnitude of the risk influence is sorted by order.

At the project planning stage, we also make WBS. WBS is a key project deliverable that organizes the team's work into manageable sections by hierarchical decomposition of the work to be executed by the project. At the project planning stage, we review all the tasks and set start and end dates of each task and efforts that are to be spent on the task.

When we identify all the tasks and make the WBS of a project, we automatically know the EVM value of the current status because the planned value (PV) and budget at completion (BAC) are calculated entirely.

In the RM process, the influence of risk is converted to "time" or "money." In this study, we convert the influence to "time" (minutes). The project stakeholders can understand the amount of influence quantitatively.

4.2.2 Quantitative Progress Management using EVM

In Stage 2, the project is managed on a weekly basis. Usually, a progress management meeting is conducted on a weekly basis. The project manager asks project members in charge to update WBS for the concerned week at the meeting. Subsequently, the actual value compared to the estimated value achieved in the project is known for a particular week. At the meeting, project members report the manager's current progress status by calculating these EVM values and problems that occurred, if any. This enables the managers to estimate the project's total cost at project completion, which is also referred to as estimate at completion (EAC)

In system development, by using a waterfall model, it has been empirically found that the risk is often explicit at process breaks. Therefore, at the progress meeting that is held at the end of the process, project members and SME conduct a risk review meeting. They reevaluate the risks according to the change of the environment at that time and update the RM ledger.

4.2.3 Risk analysis using LRA

At stage 3, we can predict whether the project will fail in the future, by using LRA. LRA is a statistical method that predicts the occurrence probability of an event from the size of accumulated data.

When we use a risk value as an explanatory variable, value that can take only a binary response (Yes / No), like the occurrence of project failure as a dependent variable, the probability of the influence on the occurrence of the failed project can be determined.

According to the basic policy (3), we decided that the whole project risk, instead of individual risk, should be set as the progress management threshold. Therefore, we decided that EAC/BAC should be set as the criteria for evaluating a project's success or failure. When the EAC/BAC exceed the specific trigger, the project manager should take appropriate action under the RM.

Organizations that conduct system development projects often have similar degrees of difficulty and similar scales. We have created repositories of PPB by accumulating project data over the past several years. We can also quantify the recoverable period for each construction period if the project is delayed.

For example, it is empirically known, "If you are projecting for 18 months, you will recover and meet the delivery date if the progress delay is less than 5% of the entire project period." We could calculate the recoverable period for each project by employing the LRA. It was found that if the period exceeds the value of (EAC/BAC- 100%), then it will lead to a delay in the delivery date. Subsequently, it will be necessary to take countermeasures that will not make the risk manifest in the schedule of recoverable limits.

4.2.4 Risk Counter Strategy

In stage 4, the project manager monitors the risk status at a progress meeting and takes appropriate risk actions if necessary. If the result of LRA exceeds the threshold, then the project manager can compensate for the project delay by immediately activating risk counter measures according to the priority measures set in the RM ledger until the EAC/BAC comes below the value EAC/BAC-100%. Then let the next PDCA cycle start.

5 EVALUATION OF THE APPLICATION IN ACTUAL DEVELOPMENT ORGANIZATION

In Section 5, a case study wherein the proposed RM method is applied at Company A and its effectiveness is evaluated. For the application of LRA, JMP®14 (SAS Institute Inc., Cary, NC, USA), which operates on Windows PC, was used.

5.1 Case Study for Embedded System Development

Company A introduced project management using PMBOK for about 10 years. Development projects comprising the basic operation of the project management using the PDCA cycle, is well established.

However, in reality, even though it was called the RM process, its focus was on creating a risk matrix and completion record for the preparation of assessment evidence. This is a situation that does not lead to effective RM.

Company A set the development process standard, based on the waterfall model that considered the entire organization. Additionally, at the time of the introduction of the PMBOK, the RM plan, the creation of the RM ledger, and the risk assessment checklist were managed within the company. The company mainly undertook derived development. The company focuses on delivering in a timely manner in a short cycle. In the cases where the delivery is delayed among QCDs, the project is labeled as a "failed project." The policy of the organization is to prevent delayed delivery.

Company A's customers do not present their requirements clearly. Therefore, the project manager in Company A must analyze customer needs and make a feasible completion plan, and formulate the budget and set the construction duration accordingly.

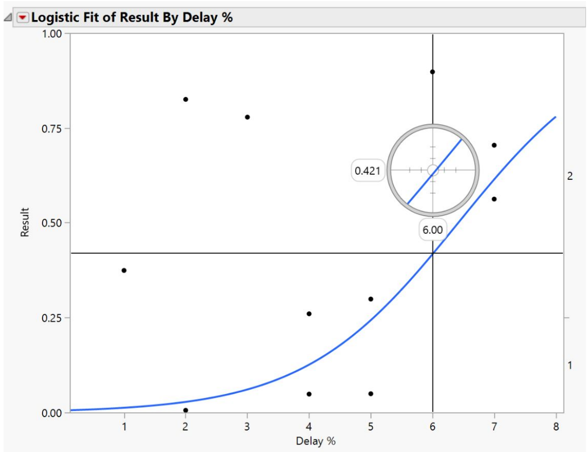

Figure 4: The Causes of Failure and its Proportion.

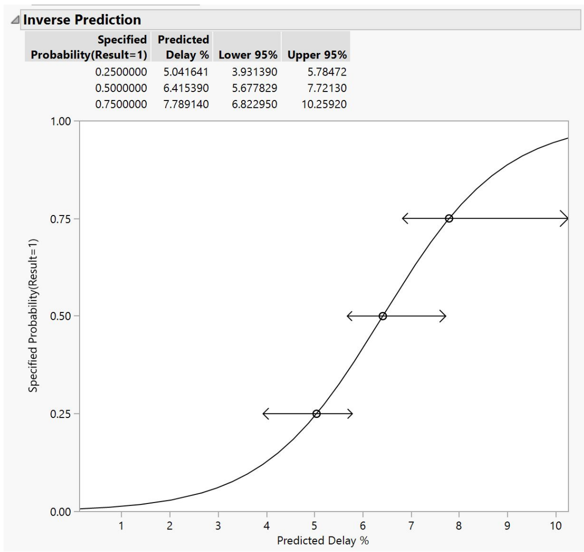

Figure 5: LRA and Inverse Estimation.

Subsequently, to implement the requirement definition, the company undertakes project planning and conducts a QA review for implementing the requirement definition and project plan.

After a discussion with the PM, SME, QA, and project members, the company rules out the related risks and prepares the RM ledger based on the risks.

The project manager holds a progress meeting on a weekly basis. The project manager asks all the project members in charge to update the WBS. Subsequently, the project manager calculate the projected EAC and EAC/BAC. Then they update the RM ledger with latest data and entire EVM value is converted into "time."

The development period at Company A is set at around 6-18 months, depending on the scale of development. We calculate the probability of project failure by using the LRA.

For example, when a project construction term is 18 months, the predicted probability of failure would be as shown in Figure 4. The cross-hair tool indicates that the prediction probability is 0.421 at the time of 6% delay. In other words, if the project is delayed by 6%, then the delivery date will be delayed with a probability of 42%.

A 42% probability is difficult to employ as a psychological milestone to activate risk countermeasures. A value at which the prediction probability becomes 50% was calculated using an inverse estimation of LRA, and it was 6.41%. Conversely, it means that "If the project is delayed by 6.41%, then there can be a 50% chance of a recovery." This state is shown in Figure 5.

Actually, if the recoverable range exceeded the threshold (like 6.41%), they activated risk countermeasures to reduce the project delay in descending order of influence until the value fell below the threshold to ensure that the value fit within the recoverable range.

5.2 Evaluation of Effectiveness

Figure 6 shows the three-year trend of delayed project delivery in Company A. Although the duration for which the project delays were observed is small, the number of projects subjected to delivery time delay has definitely been reduced. Meanwhile, Company A did not introduce any other measures during this time, but the proposed method has been introduced. Company A considered the transition, shown in Figure 6 which this can be regarded as an improvement that is achieved through the proposed method.

Figure 7 shows the transition of contingency for 3 years, after the introduction of the proposed method in Company A. Contingency is a reserve expenditure fund that can be drawn on to prevent project settlement deficit. It is preferable not to use contingency funds because it is recorded as a profit if not used. In the first year, after the introduction of our proposed method, we consumed nearly 30% of the contingency. It was suppressed to 20% or less in the third year. Since countermeasures are given priority in the order of the risk of damage due to anticipated risk, we believe that it contributed to the prevention of major deficit in projects. We confirmed that the proposed method also improves cost.

6 DISCUSSION

In this section, we discuss whether the factors presented in section 3.2 have been resolved.

6.1 Timely and Correct Risk Report

In this study, project risks at each process break are identified at the project planning stage and reviewed by PM, SME, and QA during the RM meeting. The RM ledger and WBS are updated. Subsequently, we obtain the EVM value and objectively calculate appropriate parameters for the project. At these meetings, the overall project risk and progress status are reported in a timely manner. The project manager can judge the status promptly.

Thus, nobody can reduce the number of risks or hide critical risks while reporting them; the risks are reported in an accurate and timely manner, thereby resolving the issue of delayed and erroneous risk reports.

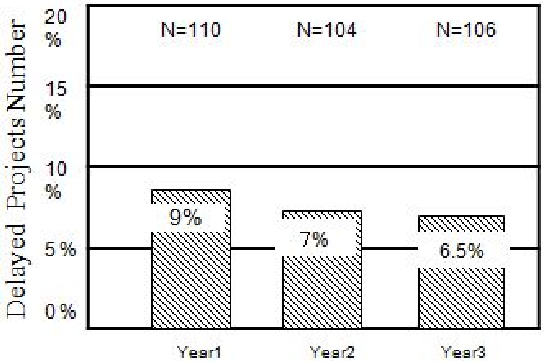

Figure 6: No. of Delivery Delayed Projects.

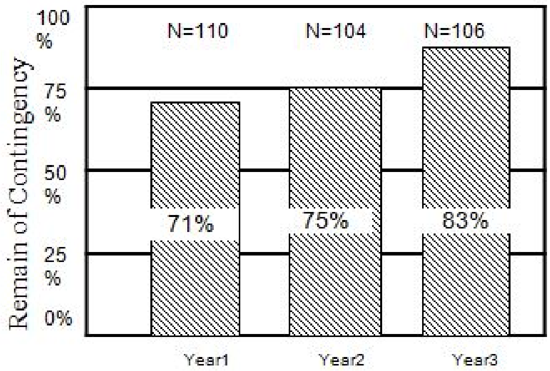

Figure 7: Transition of Contingency Budget.

6.2 PM's Risk Judgment Skill

In this study, to identify and judge risks, an SME and a QA reviewer are assigned to the project. Instead of a project manager, they support and perform RM processes, including risk identification and the activation of risk countermeasure.

In addition, risk is evaluated objectively by using parametric data to avoid the biases of project managers that might result from their assumed expertise over all the technical fields. It implies the resolution of the issues concerning skill shortage in project managers and their lack of risk-judgement skill.

6.3 RM Method in an Organization

In this study, the organization's historical project data are accumulated through the PPB. Recoverable range of each project period calculated by LRA method are accumulated.

Project managers or higher-level managers can judge risks objectively and activate risk countermeasures. The proposed RM method facilitated the unification of the organization's RM method. Thus, this method contributed toward the effective implementation of the RM method in an organization.

6.4 Full Visualization of Risk

In this study, after identifying the risk through an upstream process, we monitored the risks through weekly meetings and visualized the magnitude of an allowable recovery range by using statistical methods. Furthermore, the magnitude of the risk effect was converted into "time." We visualized the possibility of leadtime to delivery delay. Thus, the issue of full visualization of risk was resolved.

7 CONCLUSIONS

In this research study, we analyzed four actual RM processes carried out at the system development site. Additionally, the study identified the factors that contributed to delayed RM, despite the introduction of the correct RM process at the organization. Subsequently, we proposed the RM method using a quantitative process management approach that included PM, EVM, and LRA.

When we applied the method to the actual embedded development projects, we could verify and confirm the improvement effect on the reduction of the number of projects with delayed delivery times and a decrease in contingency. Thus, the proposed method is considered potentially effective.

This proposed method can be introduced easily in any organization implementing process improvement. In the future, it is necessary to increase case examples, evaluate effectiveness, and make improvements to the existing RM process.

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