An Empirical Study of Development Visualization for Procurement by In-Process Measurement during Integration and Testing

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ABSTRACT

This study describes a new method of development visualization along with empirical evidence of its usefulness.

Typically, development activities such as program design, programming, and unit testing are not disclosed to the procurement organization (project owner). However, during integration and testing, various issues require collaboration between the procurement organization and developers. When this occurs, it is important to make the development process visible. Recent reports indicate the usefulness for project management of various in-process project measurements which allow visualization of the formerly invisible software project progress [1]- [6].

Based on this background, the authors investigated a case study where in-process measurement during the integration and test phase helped to make development issues visible. In this study, data obtained from the integration and testing phase were compared to a development process model. This model was based on the author's experience, and provided a vivid picture of the development activity. By applying in-process measurements in collaboration during the integration test phase, the development activity was clearly visualized, and the procurement organization understood problems.

1. INTRODUCTION

Originally the software development process is not easily visible. Since the software development process is invisible, not only does it make suitable decisions in project management impossible, but especially in procurement type developments, if it is hard to share project progress information between procurement side and software vendors then it becomes very difficult to perform suitable cooperation.

By visualizing the software development process using various methods, both sides can share the visualized information, arrive at suitable decisions according to each role, and provide smooth formation of agreements as required. The breakthrough of visualization and information sharing about the development phase requires information that tends to be closely held inside a vendor organization and tends to constitute a black box.

In this research, authors plan this breakthrough by applying the method of the automatic in-process measurement which authors have so far studied to integration test process and system test process of following a development phase, and applying that measurement result to one process model of the development phase drawn from years of authors' experience.

At first this paper introduces a development software process model published by the authors. Then, it introduces a measurement method based on a project measurement platform tool named the Empirical Project Monitor (EPM). Next, it describes a target project for measurement. Following that, the article describes how development issues were visualized using measurement data. The case study applied this process to the development model and showed that issues with the project became visible. Finally, the paper summarizes the usefulness of the measurements and study on issues of project visualization, and proposes a model process for measurement and feedback in integration and testing.

2. A DEVELOPMNT PHASE PROCESS MODEL

2.1 IT Project Visualization Activity: *"MIERUKA"*

During the past four years, the authors have organized a software engineering research task force composed of persons with many years experience in the software development field, which has developed an integrated method and tools for visualization of the software process. This method was named *"MIERUKA,"* which is the Japanese word for visualize, and the research results were distributed as a series of published books (in Japanese, now partially translated into English) along with software tools from the SEC/IPA organization [7]-[14]. This method defines the total process as comprised of three phases, the requirements and specifications phase, the developments phase, and the integration and testing phase. This method also defines a process model for the development phase.

2.2 Structure of the Process Model

The process model for the development phase defines 14 actions, or micro processes, arranged in four functional blocks. This is shown in Figure 1 [8]. Considering a time axis extending to the right from the left margin, the development phase is located between the requirements and specifications phase (requirements phase) and the integration and testing phase (integration phase). Project planning (project management), and project rule activities pass through these three phases. Four functional blocks show main activity of this phase. Ten arrows show interaction activity between these activities.

The measurement target project described after was not quite recommended along with the model shown here. Then correspondence of the general process name used in the measurement target project and our model is shown in figure 1. For example, number one, Requirement Function Verification corresponds to the System Architecture design (SA). Number six, Software Design corresponds to the User Interface (UI), the System Structure (SS), and the Program Structure (PS) design. Number 10, Programming and Unit Test correspond to Programming (PG) and Program Test (PT). Integration Test (IT), System Test (ST), and Operational Test (OT) from the integration and testing phase follow this.

During the entire process, collaboration between procurement organization and the developers is supported by process visualization and information sharing. Each of the 14 actions is described below.

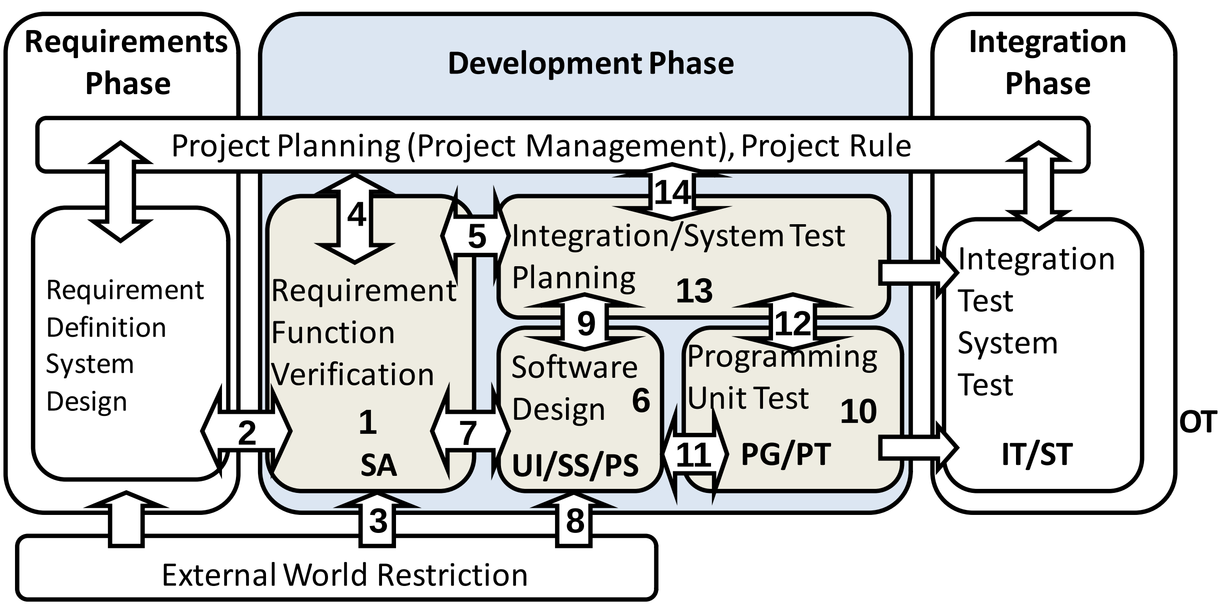
1) Verify requirements functions

In this activity, review and verification of products from the specification and requirements phase is conducted. This includes products from requirements definition, system design, project planning, and the system architecture design (SA). This activity often identifies a lack of decision about generalized criteria for "what," "how far," and "in what way" in the specification and requirements phase. During this activity, we recommend checking subjects that should be determined during specifications and requirements such as the request for proposal (RFP), cost, quality, customer, risk, communication and the legal issue related to the procurement contract.

A complete review with all related persons is a practical method for conducting this verification. To make this activity most successful, close collaboration between the procurement organization and the developers is important.

2) Reconfirm requirements definition

Retrace and correct the requirements definition and system design to remove defects found in Requirements Function Verification (1). This may be difficult work, however projects that neglect it encounter trouble. This work may require management decisions such as re-examination and renegotiation of contracts.



SA: System Architecture, UI: User Interface Design, SS: System Structure Design, PS: Program Structure Design, PG: Programming, PT: Program Test, IT: Integration Test, ST: System Test, OT: Operation Test

Fig.1 Development Phase Process Model [8]

3) Re-examine requirements definition and system design based on implementation verification

Verify results of the verification and changes described in (1) and (2) by considering the system implementation from the viewpoint of customer characteristics and external restrictions. These points must be verified from the viewpoint of various experts and responsible individuals related to the target system to develop necessary strategies. As part of this, procurement organization must also make positive contributions.

4) Re-examine project planning based on requirements and design changes

Changes identified and made in (1) to (3) must be reflected in project planning. Generally, these changes may be difficult to perform, and require collaboration from procurement organization, project management, and developers. Management decisions may be required.

5) Make integration and system test scenarios

Based on the information and changes described in (1) to (4), develop integration test (IT) and system test (ST) scenarios. This action should be started early in the project.

6) Produce software design

Based on the results of (1) to (3), the developers should produce the software design. This includes the user interface design (UI), the system structure design (SS), and program structure design (PS). Doing this work may make defects in the previous work visible, which requires rapid escalation and resolution.

7) Re-verify requirements definition based on software design

Whenever defects are detected during software design (6), the requirements definition should be re-verified. The influence of this action may be far-reaching and un-localized, so follow up across the project is required. Additionally, as described in (9), such changes should be reflected in the test scenario. Contribution by the procurement organization is essential.

8) Verify feasibility based on software design

Verify and confirm the various constraint conditions described in the abovementioned 6) the Software Design. Review various restrictions and recode them in documents. Result of the verification and the recoded document will be utilized in subsequent processes.

9) Prepare integration and system test scenarios

Incorporate results of the software design (6) into the integration test (IT) and system test (ST) scenarios. This action should be started as early as possible.

10) Prepare programming and unit tests

Based on results of the software design (6), prepare programming and unit tests. This activity has a tendency to be a black box performed by each responsible person. However, providing visibility into this activity is important, especially since defects detected in this activity may force revision of the software design (6).

11) Return to software design based on programming and unit test results

Defects detected during preparation of programming and unit tests (10) cause a return to the software design (6). This includes maintenance and consistency of documents. It is important to maintain conformity between programming activities and documentation.

12) Feedback from unit test results to integration and system test scenarios

Results from preparation of programming and unit tests (10) should be incorporated into the integration and system test scenarios prepared in (9).

13) Plan integration and system testing

On the basis of (1) to (12), make plans for integration and system test scenarios. There is a tendency to leave this entirely up to the development vendors, however, contributions by procurement organization can help assure that application, service, and operations viewpoints are given adequate support.

14) Readjust project plan

Although frequently extremely difficult, when necessary, it is essential to execute this action. Collaboration between the procurement side and the development vendor is necessary.

3. PROJECT MEASUREMENT PLATFORM EPM

Empirical Project Monitor (EPM) is a software project measurement platform designed to execute automatic project measurement. The original model was developed in a Japanese software engineering research project named Empirical Approach to Software Engineering (EASE) project (2003–2008) under the form of industry and academia collaboration. Thereafter, EPM was strongly enhanced in function and quality to meet the commercial software product levels by SEC/IPA, which had been established since 2004 as a governmental research organization for software industry promotion. The basic functions are as shown in Figure 2. This system automatically collects software process- and product management-related data from the configuration management system, the bug tracking system, and the mailing management system in the software development environment.

Further, it analyzes and visualizes these data into useful forms for project management. After the usefulness of EPM was verified in certain verification projects, it has been adopted in over 70 real industrial development projects and evaluated [1][2][12]-[16].

The measurement and visualization targets in EPM include, for example, source line of code number transition, cumulative bug number transition, remaining bug number transition, average bug residences time transition, and mail number transition. Further, EPM is able to analyze and visualize administrative information that is stored in the configuration and bug tracking systems into useful form for project management.

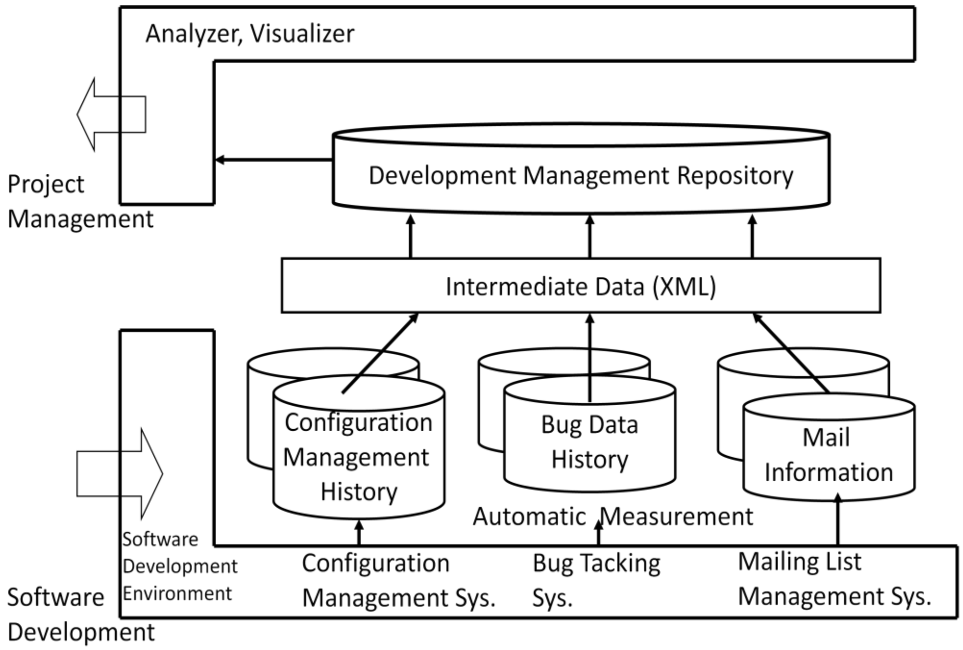


Fig.2 Structure of EPM [1][2]

4. OUTLINE OF THE TARGET PROJECT AND MEASUREMENTS

4.1 Target Project

For this case study, the target project was a midscale system requiring relatively high reliability ordered by a user company to a software development vendor company. The development project was developed in cooperation by the prime contractor system integrator company along with some partner vendor companies in a hierarchical structure commonly used in the Japanese software industry. The user company had been significantly involved in the requirements definition and the operational testing phases. However, during the development phase, their project management role was reduced to hearing declarative style reports from the vendor companies, a common change in participation for Japanese user companies.

The authors had used EPM to automatically collect measurements of this project during 16 weeks of integration testing (IT) and system testing (ST) which composed the integration and testing phase. The specific measurement targets were configuration management and bug tracking data. The collected data was analyzed after completion of the integration and testing phase. During the test (IT/ST) phase, there was no feedback from the data analysis to project management.

4.2 Collected Data and Visualized Items

In this case study, various data were collected from the configuration management system and the bug tracking system. Table 1 shows the collected data and examples of visualized items. Transition graphs made information about the source code visible during the integration test (IT) and the system test (ST) phase. Analysis of the bug reports made various characteristics of the product visible.

The meaning of “undetected bug cause” is the reason why the bag was undetected. For example, slip out of test, slip out of test item, so on and it was recorded into the bug report until the bug was closed.

Table 1 Collected Data and Visualized Items

Data Source	Collected Data	Examples of visualized items
Configuration Management System	Check-in Timing	Check-in Timing
	Check-out Timing	Check-out Timing
	Check-out Frequency	Check-out Frequency
	Sourse Line of Code(SLOC) at Check-in Timing	Transition Chart of Accumulated SLOC
Bug Tracking System	Bug Detected Date	Transition Chart of Accumulated Bugs
	Bug Status	Distribution Chart of Bug Status
	Bug Closed Date	Transition Chart of Remaining Bugs Transition Chart of Average Bug Resolution Times
	Bug Introduction Phase	Transition Chart of Bug Introduction Phases
	Bug Cause	Distribution Chart of Bug Causes
	Undetected Bug Causes	Distribution Chart Of Undetected Bug Causes
	Bug Resolution Reports	Distribution Chart Of Destination Modules For Bug Resolution Requests
		Distribution Chart Of Source Modules For Bug Resolution Requests

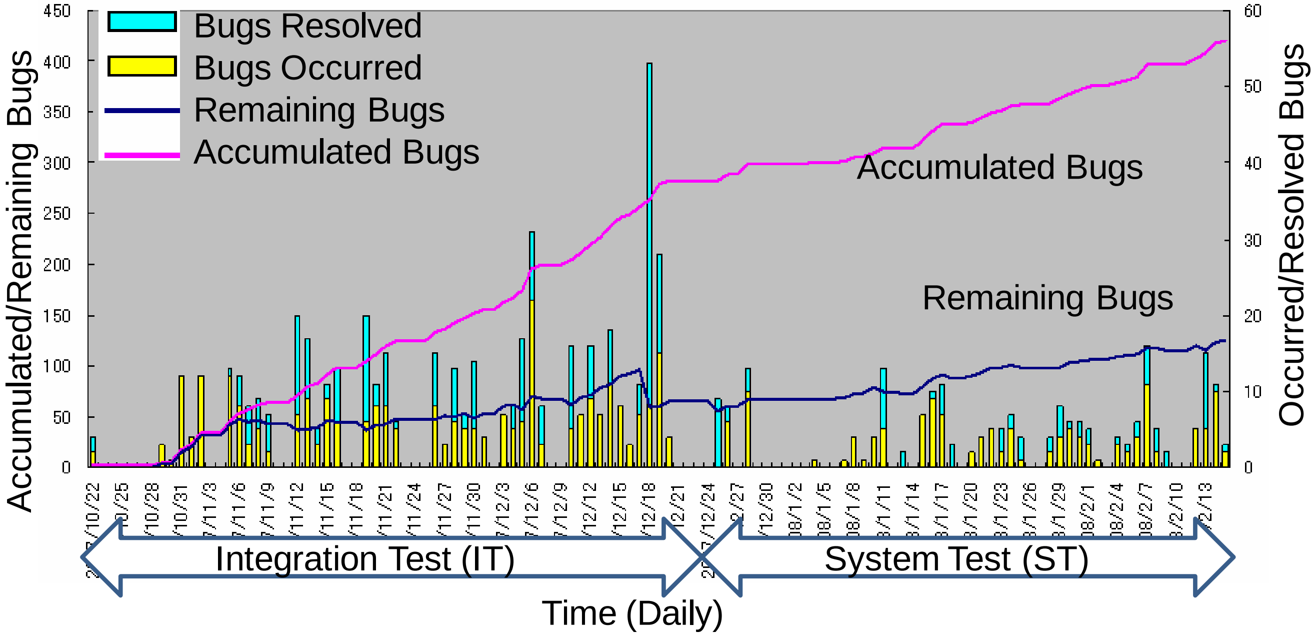


Fig.3 Daily Bug Information Transition Chart

5. MEASUREMENT RESULTS

5.1 Visualized Phenomena

1) Overall situation of the measured process

Figure 3 shows the transition chart of the daily bug information over the 16 weeks. This transition chart corresponds to the integration test (IT) and system test (ST) phases following the programming and unit test (PG/PT) phase. Measurements were terminated two weeks prior to the termination date of the ST phase. In total, 420 bugs were detected. The transitions in the cumulative bug numbers clearly display energetic action on tests during this period. From the transition chart of the remaining bug numbers, it is also clear that there are remaining quality issues. These quality issues were observed in all phases as the number of remaining bugs never reached zero, and remaining bugs from the IT phase were carried over into the ST phase. The histograms showed daily detected and resolved numbers of bugs. The total number of bugs detected in the ST phase was relatively small compared to the number of bugs detected in the IT phase, however, the accumulation of bugs makes it difficult to close out the ST phase on schedule.

Figure 4 presents the check-in timing (vertical line), the check-out timing, and the frequency (histogram) during this phase.

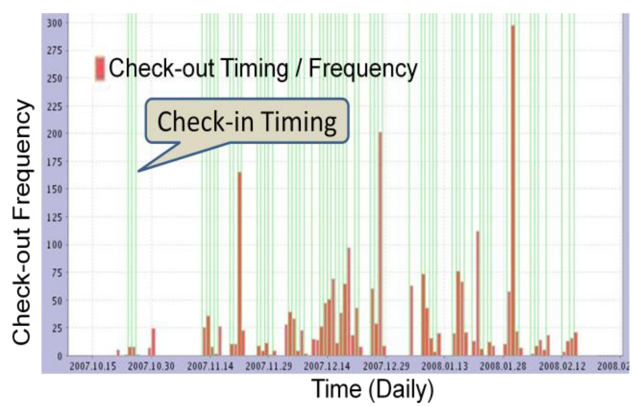


Fig.4 Check-in Timing & Check-out Timing/Frequency

2) Integration test (IT) phase situation

Figure 5 is a pareto graph showing the number of bugs introduced in different phases that were detected in the IT phase. The number of bugs introduced is greatest in the programming (PG) phase and the system structure design (SS) phase, followed by the integration test (IT) phase itself. Characteristically, various issues were associated with the system structure design and programming phase, however, considerable degradation was observed in the integration test phase.

Figure 6 aggregates bug causes from the bug reports of the integration test phase. Characteristically, the largest number of bugs was attributed to "specification." This suggests that there were issues in the specification verification process, which should have detected such bugs well before the integration test phase.

Figure 7 aggregates causes for undetected bugs from the bug reports of the integration test phase. These results suggest that there were issues with the unit test phase.

Figure 8 aggregates bug causes using a different categorization. Based on this analysis, serious bug cases such as "logical error," "interface error," and "data definition error" are the three major types of error. This analysis also suggests that there were issues with the design and specification verification phase, rather than in the programming and unit test phase.

Figure 9 is a crossing analysis graph that shows the bug causes in each phase. This analysis points out issues with the system structure design (SS) phase.

Bugs detected in the IT phase did not occur homogenously in the system. Figure 10 shows the bug resolution request destination modules, while figure 11 shows the bug resolution source modules. When the integration and the system test are done for each module, the module by which the bug was discovered, and the module of the fundamental target for repair are not always the same. This first bug discovered module is called bug resolution request module and the module for repair is called a bug resolution destination module. This information was recorded into the bug report until the bug was closed.

These figures clearly indicate that three or four modules (e.g. A, B, C, D or E) had high numbers of bugs. In further analysis, the authors analyzed bug transitions in the top three modules using the data search function of EPM. Figure 12- figure 14 are multiplex line graphs that present transition charts of the accumulated numbers of bugs, remaining numbers of bugs, and the average bug resolution times for these top three modules. While each module clearly has energetic test and debugging activity, the number of detected bugs was increasing rapidly prior to termination of the test phase. Also, in the case of modules B and C, the ST phase was started before the number of remaining bugs detected in the IT phase reached zero.

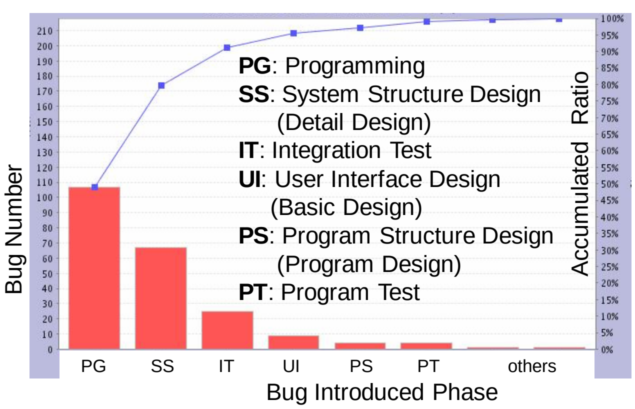


Fig.5 Bug Introduced Phase (IT phase)

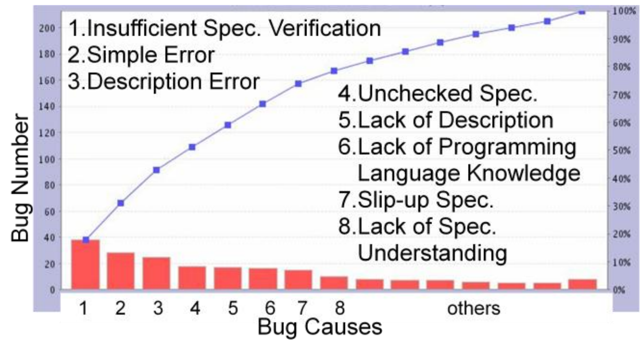


Fig.6 Bug Causes Distribution (IT phase)

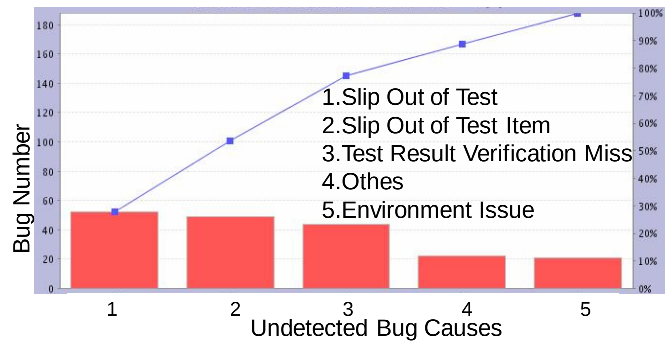


Fig.7 Undetected Bug Causes (IT phase)

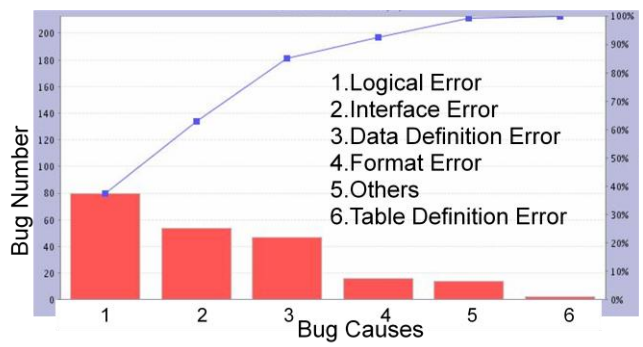


Fig.8 Bug Causes (IT phase)

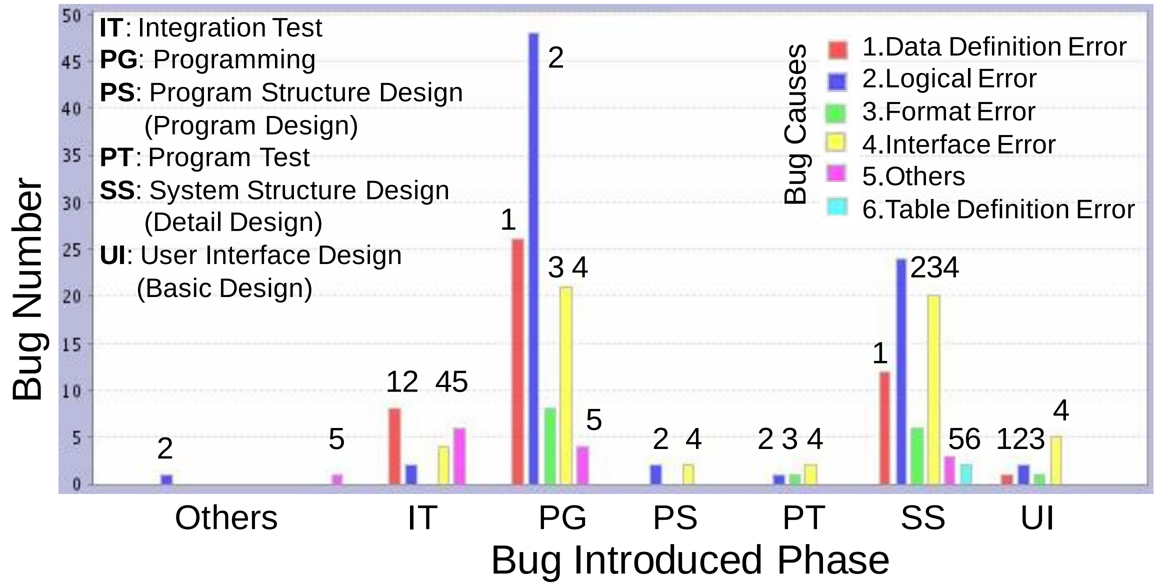


Fig.9 Bug Causes in each Phase (IT phase)

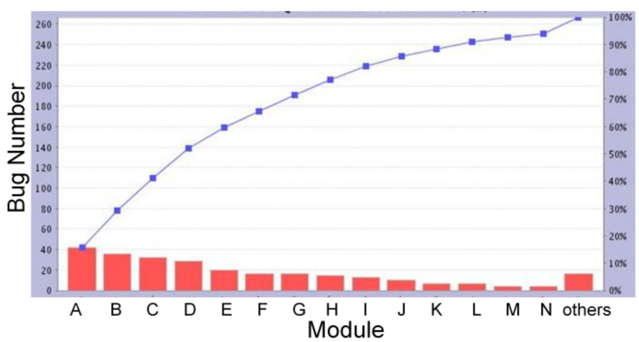


Fig.10 Bug Resolution Request Destination Module (IT phase)

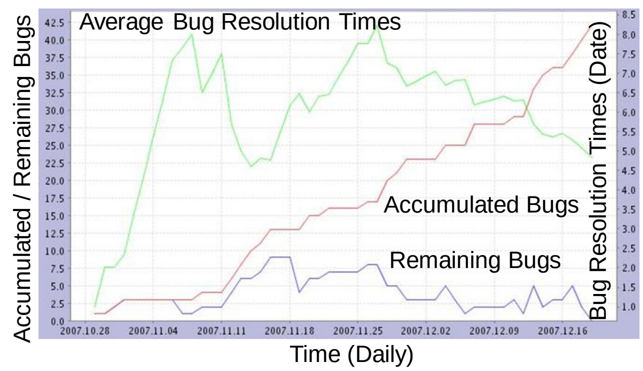


Fig.12 Bug Number Transition (Module A) (IT phase)

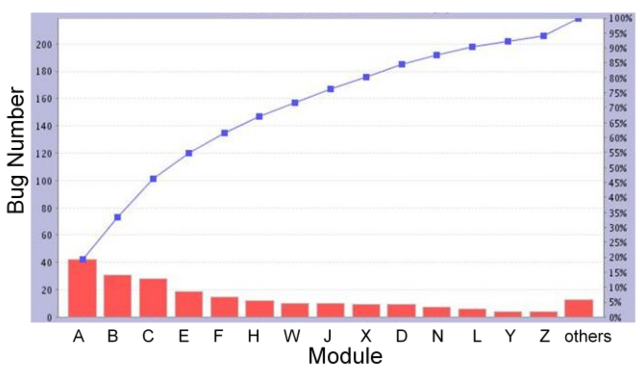


Fig.11 Bug Resolution Request Source Module (IT phase)

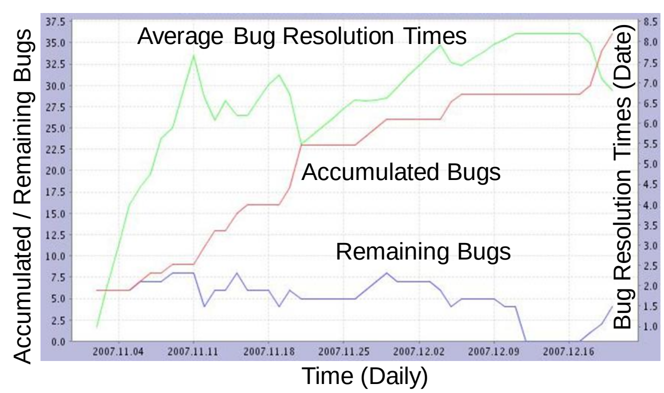


Fig.13 Bug Number Transition (Module B) (IT phase)

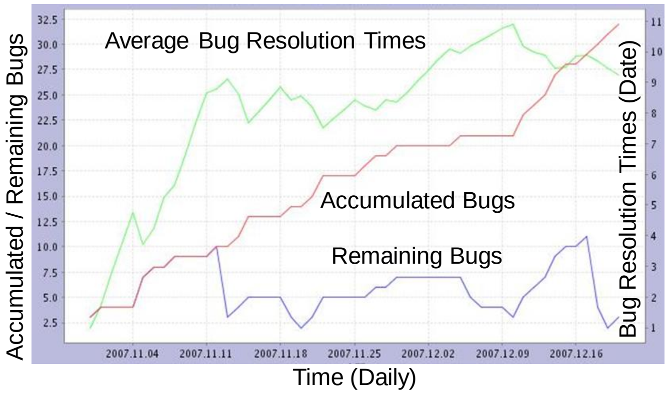


Fig.14 Bug Number Transition (Module C) (IT phase)

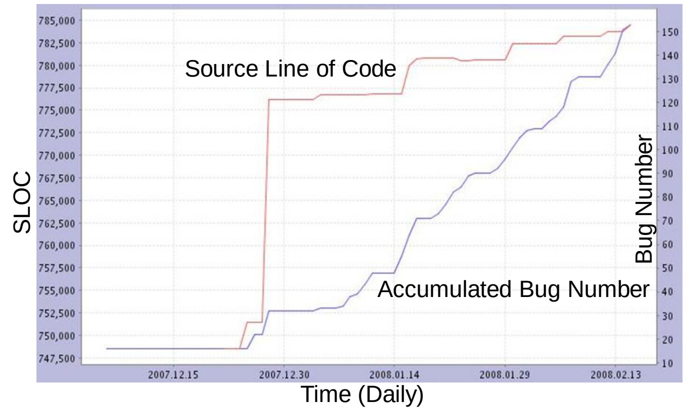


Fig.15 Source Line Code Number Transition and Accumulative Bug Number (ST phase)

3) System test (ST) phase situation

Figure 15 provides a transition chart showing the developed number of source lines of code and the accumulated number of bugs in the ST phase following the IT phase. Despite the test phase label, it is clear that the number of source lines of code was increasing and that energetic debugging activity was being performed. The last data measurements are from two weeks before the deadline of the ST phase. At this point, bug detection was continuous and it appeared difficult to complete this phase on schedule. Figure 16 shows the final situation of this measurement, which includes the presence of many unsolved bugs.

Figure 17 illustrates the phase of introduction attributed to each bug. Various bugs introduced in the system structure design (SS) and user interface design (UI) phases were detected, and several of these bugs were unsolved.

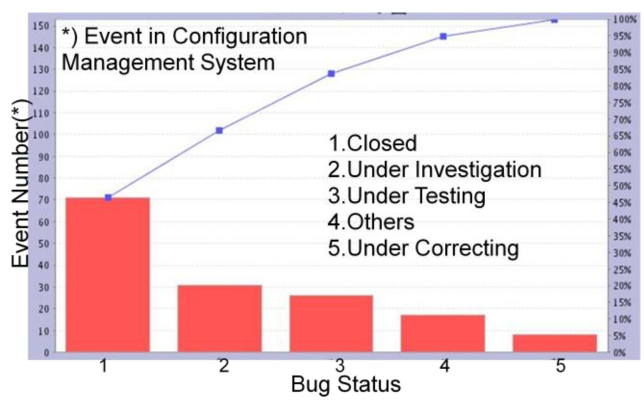


Fig.16 Bug Status at the End of Measurement

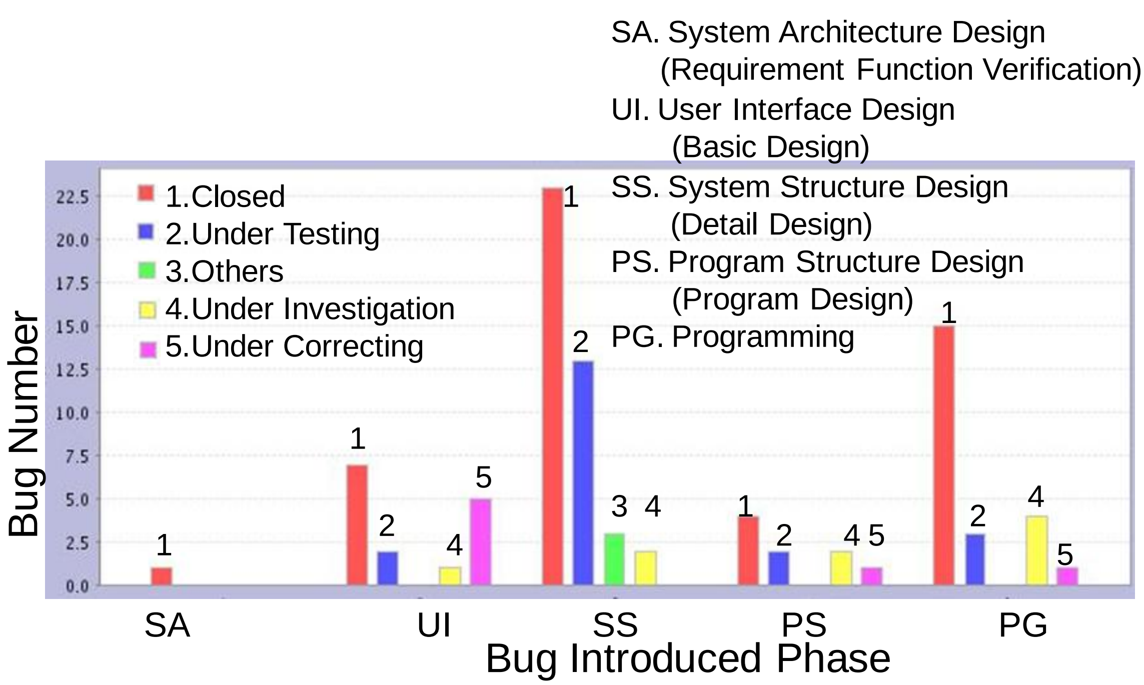


Fig.17 Bug Status by each Bug Introduced Phase (ST phase)

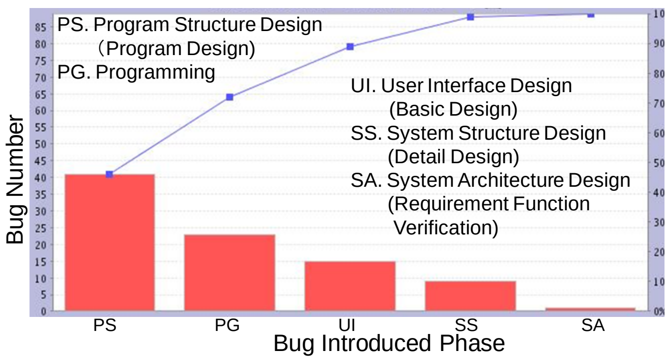


Fig.18 Bug Introduced Phase (ST phase)

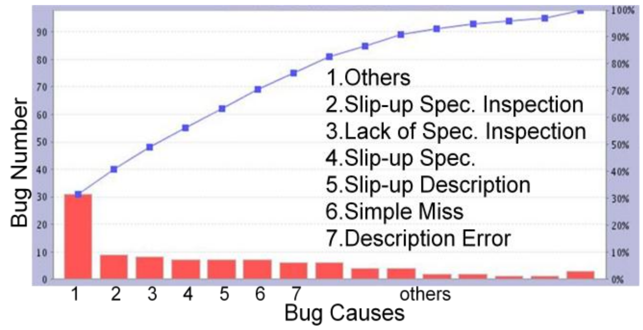


Fig.19 Bug Causes Detected in ST phase

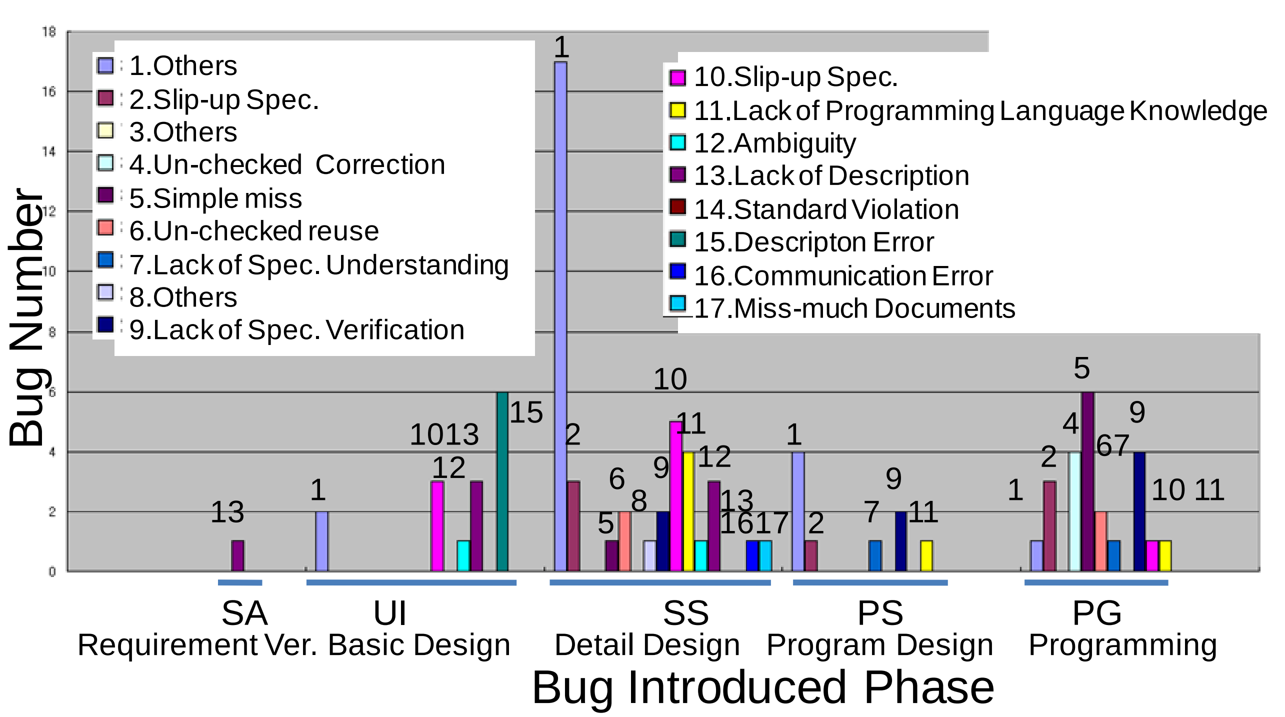


Fig.20 Bug Causes by Introduced Phase (ST phase)

Figure 18 provides a pareto chart of the phase of introduction of bugs. This indicates issues in program structure design (PS), programming (PG), and user interface design (UI) phases.

Figure 19 analyzes the bug causes. Again, the presence of many "specification" related bugs suggests issues with the requirements verification phase and the design phase.

Figure 20 analyzes bug causes in terms of phase of introduction. This analysis suggests various issues in the system structure design phase (SS).

Figure 21 accumulates the total bug causes detected in the ST phase. Similar to the IT phase, essential errors such as Interface error, Logical error, and Data Definition error occur in the greatest numbers.

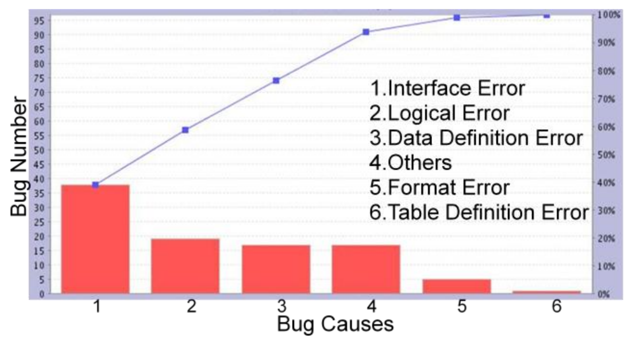


Fig.21 Bug Causes (ST phase)

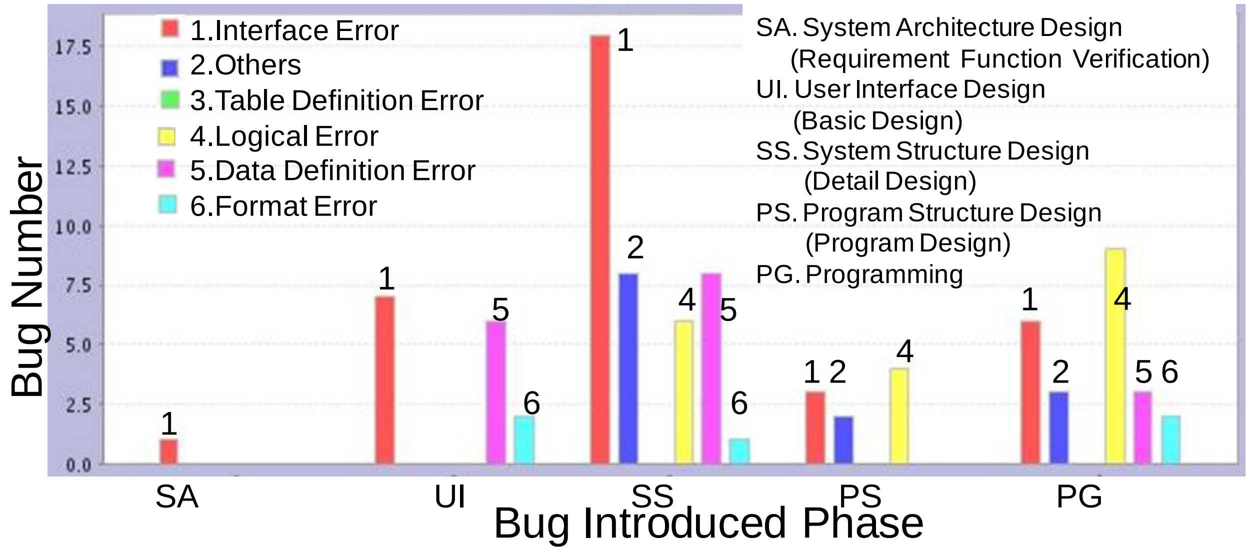


Fig.22 Bug Causes by each Introduced Phase (ST phase)

Figure 22 shows bug causes by bug introduced phase; it is clear from this figure that there are various essential bugs introduced in the System Structure Design (SS), the User Interface Design (UI) and the Program Structure Design (PS) phases.

Further, in the ST phase, bugs were not detected homogeneously. Figure 23 shows detected bugs in the ST phase by program modules. For example, in module B, a lot of bugs were detected at both the IT and ST phases.

Figure 24 shows the bug number transition of module B. Various bugs were detected in the ST phase and the number of unsolved bugs increased; this makes the termination of the phase on time appear difficult.

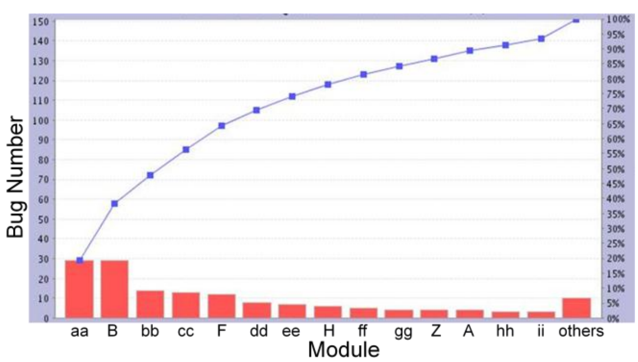


Fig.23 Bug Number by each Module (Detected in ST phase)

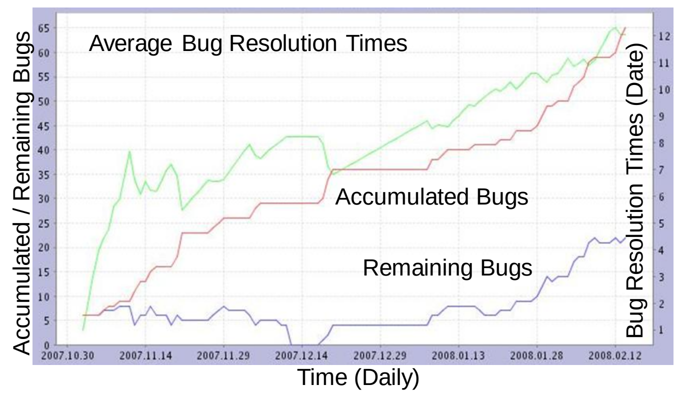


Fig.24 Bug Number Transition of Module B

5.2 Comparison with the development phase process model

Typically, the actual status of the development phase is largely a black box for procurement. However, as described above, a number of issues with development were made visible by comparing the results of EPM measurements with the development phase process model. Figure 25 includes figure numbers from above that suggest the presence of various issues in each phase. We do not know whether this target project used the process shown in figure 1 or not. However, considering this model as a logical model, each of the actions or micro processes must be accomplished. Based on measurement results from the IT and ST phases, the actions or micro processes in the development phase were not effectively performed.

The results of this analysis indicate that bugs detected in the integration and testing phase were introduced in the programming and unit test phases, but also in the software design phases. Additionally, various bugs were introduced due to insufficient verification of the requirements definition. These results suggest

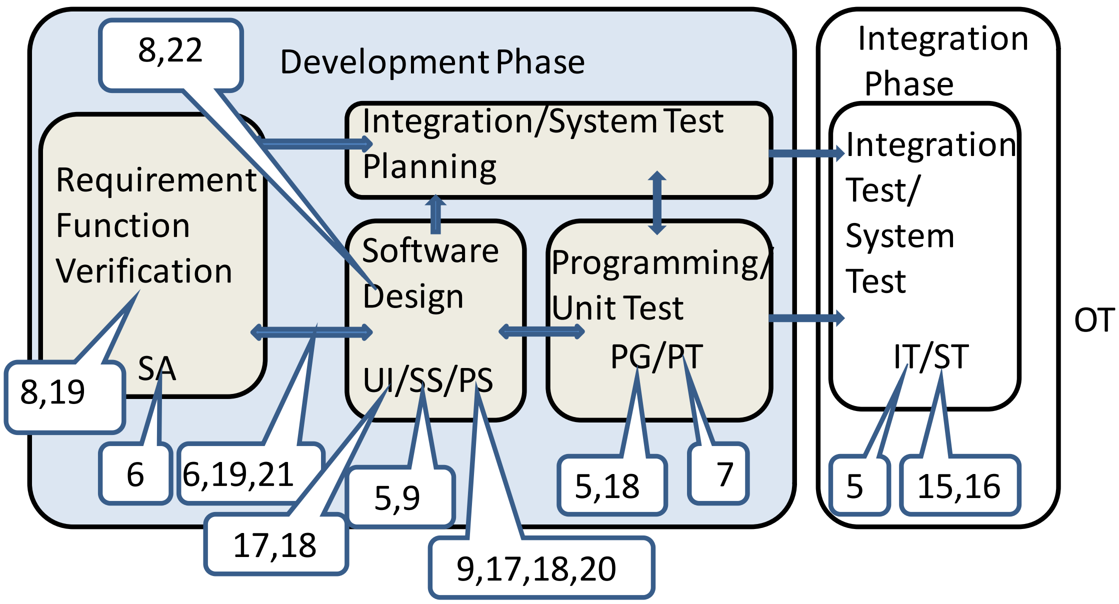


Fig.25 Issue Suggested Micro-process in the Development Phase (Corresponded Figure Numbers)

that feedback between the activities or micro processes during the development phase was insufficient.

6. STUDY ON THE USEFULNESS OF MEASUREMENTS

Figure 26 presents the model for measurement and feedback used in this case study along with the V-model suited the view of ISO 12207.

1) Execute in process measurements during the integration and testing phase and analyze the results.
2) These measurements make visible issues with the development phase and the integration and testing phase.
3) Issues associated with the development phase can be used as part of the transition decision between a development project and subsequent operations, which is an important part of project management.
4) Also, visibility of these issues can help make operation and maintenance decisions.
5) Finally, visibility of these issues may be used to make decisions about later projects and process improvement.

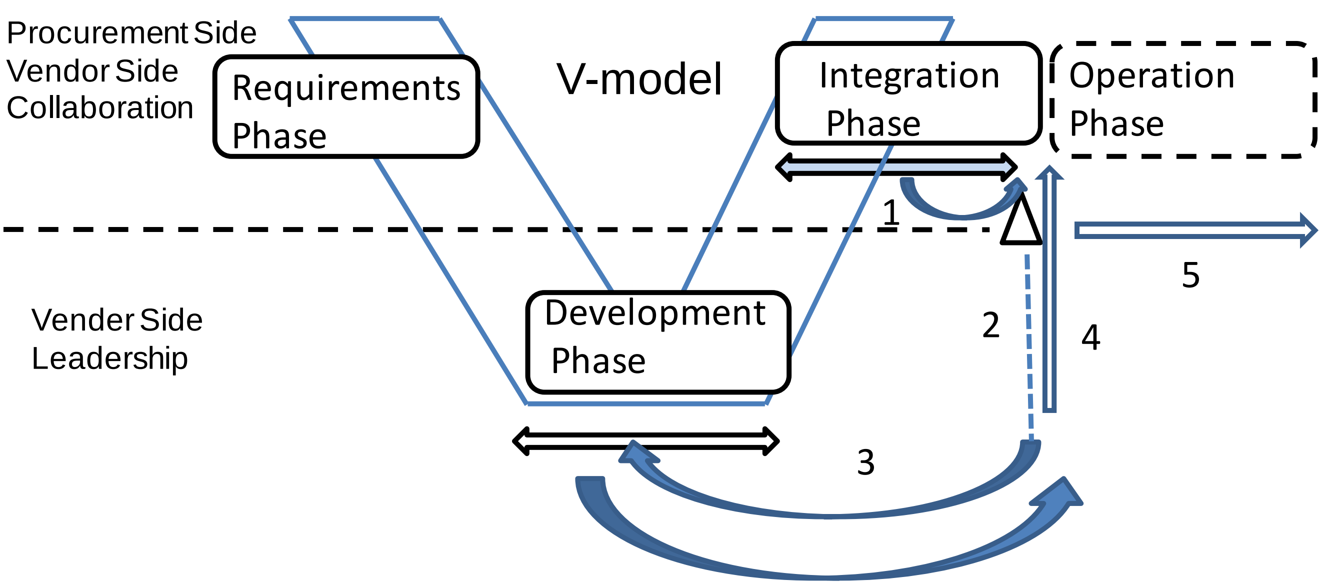


Fig.26 Measurement and Feedback Model suited to the V-model view

As the issues uncovered in this case study showed, insufficient verification of requirements for some modules during development, additional design reviews, and similar problems may require readjustment of project planning. However, to execute these actions, aggressive collaboration with procurement is essential. Such changes cannot be effectively enforced while maintaining the black box status of the development process.

This case study verified that project visibility based on in-process measurement data collected by platforms such as EPM allows information sharing between procurement organization and developers, to support proactive project management. This case study presents an approach to satisfying the empirical information needs to allow such collaboration.

Finally, the use of project measurements and visualization of analysis results indirectly warns against poor development activities. When the development phase is removed from the black box, transparency of the process and product allows compliance with standardized process models, which can be expected to yield high reliability and productivity.

7. CONCLUSIONS

For both waterfall and procurement software projects, although it is generally agreed that collaboration between procurement organization and developers provides the best environment for development, there is a tendency for the development process to become a black box to procurement organization. This empirical case study verified that in-process measurements during the integration and testing phase helps make various issues from the development phase more visible and provides useful information for project management and process improvement. The case study used the in-process measurement platform called EPM along with a development phase process model called *"MIERUKA"* that was defined by the research task force, made up of professionals with several years experience in this field.

The case study provides evidence of the effectiveness of in-process measurement. It also provides evidence for the effectiveness of using in-process measurement of one phase to help make visible problems in earlier phases. The case study also demonstrated the usefulness for project management of combining the results of in-process measurement with a process model. Finally, the case study demonstrates one way to use a development phase process model based on accumulated experience.

This case study, along with previous studies, highlights the usefulness of in-process measurements for various stakeholder groups involved in software development. For example, such measurements provide visibility into the development process for the procurement organization and project management. Such measurements also provide visibility and communications for prime contractors and subcontractors, which is an approach commonly used in Japan that is growing increasingly complicated with offshore development.

Combining information from software project repositories, process models and standardized descriptions such as UML diagrams, and in-process measurements can provide procurement, project management, and developers with unprecedented visibility into the software process from specifications and requirements through development and into integration and test. Combining this with the software tag approach being developed in the StagE project will extend the availability of this information even further, allowing maintainers and users to benefit from this increased visibility into the former black-box of development [17]-[19]. Further, the use of automated support systems such as EPM to perform the in-process measurements minimizes the impact on developers by extracting the necessary information from existing tools such as source code version control systems, defect tracking systems, and project email lists.

Although this is only a single case study, the evidence points toward the usefulness and effectiveness of performing such in-process measurements using an automated system such as EPM, combined with process models and other descriptions of the software development project drawn from professional experience. Especially when compared with similar information extracted from a repository of data about software projects, this provides a strong basis of information for making decisions that are empirically based.

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