Motivation Process Formalization and Its Application to Education Improvement for the Personal Software Process Course

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SUMMARY Software engineering education at universities plays an increasingly important role as software quality is becoming essential in realizing a safe and dependable society. This paper proposes a practical state transition model (Practical-STM) based on the Organizational Expectancy Model for the improvement of software process education based on the Personal Software Process (PSP) from a motivation point of view. The Practical-STM treats an individual trainee of the PSP course as a state machine, and formalizes a motivation process of a trainee using a set of states represented by factors regarding motivation and a set of operations carried out by course instructors. The state transition function of this model represents the features or characteristics of a trainee in terms of motivation. The model allows a formal description of the states of a trainee in terms of motivation and the educational actions of the instructors in the PSP course. The instructors are able to decide effective and efficient actions to take toward the trainees objectively by presuming a state and a state transition function of the trainees formally. Typical patterns of state transitions from an initial state to a final state, which is called a scenario, are useful for inferring possible transitions of a trainee and taking proactive operations from a motivation point of view. Therefore, the model is useful not only for improving the educational effect of the PSP course, but also for the standardization of the course management and the quality management of the instructors.

key words: personal software process, motivation, state transition model, organizational expectancy model, education improvement

1. Introduction

Society depends on many devices and services realized by software. Software defects can lead to not only inconvenience and the loss of business opportunity but also problems relating to information security and safety. Software quality is essential to business success and a safe and dependable society.

The Personal Software Process (PSP)\(^{[1],[2]}\) developed by Watts S. Humphrey is a self-improvement process that a software engineer can employ to manage his/her own development process by him/herself and to improve his/her software quality using his/her own process data. To satisfy society’s demand for high quality software, several universities and institutions pioneered the introduction of the PSP to education programs\(^{[3]–[8]}\). In cooperation with the Software Engineering Institute (SEI) of Carnegie Mellon University, the Kyushu Institute of Technology (Kyutech) trained SEI-authorized PSP instructors, and officially introduced software process education based on the PSP as a part of its graduate school education program\(^{[9]}\).

The PSP course offered by Kyutech began in the 2007 school year, and 55 trainees took the course until the 2012 school year. The quality indicators of the trainees, such as the defect density, significantly improved during the course. These results show that it is possible for graduate students to acquire knowledge and skills required for the improvement of software quality, and reveal that the PSP is an effective tool for such purpose. However, not all trainees were able to complete the course\(^{[10]}\). For example, only about 20 percent of the trainees completed the course in recent school years, while it is said that about 50 percent of experienced software engineers in industries complete. The low completion rate of the course is undesirable in terms of not only the inefficiency of software process education but also the trainees’ sense of failure, and there is a strong need to improve the course management.

Individuals or organizations often fail to introduce new technologies or methods that would bring improvements in business. Moreover, even if a newly introduced technology or method appears to be successful initially, its performance may decline in time. In general, when an individual or organization challenges the introduction of new technologies or methods, it is necessary to appropriately motivate an individual working on the introduction. The PSP course is a practical training course on software processes and includes a high-load of exercises. The motivation of the trainees is an important factor of the course completion.

To use the motivation factor of trainees in course management, it is necessary for instructors to observe trainee behavior and performance, presume the trainee’s mental states in terms of motivation, and take appropriate actions according to the mental states. There have been several studies on motivation in education. Adachi\(^{[11]}\) proposed a teaching method based on Expectancy Theory in industrial arts education. Nagata et al.\(^{[12]}\) studied the influence of organizational factors based on the Organizational Ex-
expectancy Model [13] in athletic sports teams and showed that organizational factors influence motivation. Koike [14] showed factors influencing intrinsic motivation based on Self-Determination Theory. However, there is no sufficient framework to represent formally the states of trainees and changes in the states in terms of motivation and utilize them for the improvement of course management.

The state transition model of a motivation process [15] based on the Organizational Expectancy Model is useful for the analysis of a process in introducing and establishing new technologies or methods. The Organizational Expectancy Model models interactions between an executing process and its monitoring and control process of an environment or organization in terms of motivation process. Because there exists the similarity between the structure of these processes in an organization and the structure of a learning process of students and a teaching process of teachers in an university, it seems that the Organizational Expectancy Model can be applied to software process education in an university even though the parameters of the model, such as the content of rewards, are different between working environment and education environment. The state transition model based on the Organizational Expectancy Model has been applied to the PSP course based on this idea, and the Baseline-State Transition Model (Baseline-STM) has been proposed for the course. However, the Baseline-STM assumes that knowledge and skills are acquired by the trainees according to a supposed or ideal scenario in the PSP course. Therefore, it cannot be is improved to establish the PSP course in practice.

In this paper, a practical state transition model (Practical-STM) of a motivation process in the PSP course is defined precisely according to the authors’ experiences as instructors. The Practical-STM is intended to extract precisely the features or characteristics of a trainee regarding motivation, and presume a state and a state transition function of the trainee from an instructor’s point of view during the course. The precise presumption is useful for the instructors to decide effective and efficient actions that will assist trainees to complete the course with high performance. Section 2 describes the structure and state transition model of a motivation process based on the Organizational Expectancy Model, and Sect. 3 introduces the Practical-STM of a motivation process in the PSP course. Section 4 describes typical motivation scenarios in the Practical-STM and the application of the Practical-STM to improve education. Section 5 discusses the applicability of the model and future works.

2. State Transition Model of the Motivation Process

2.1 Motivation Process and Its Structure

Motivation theory can be roughly divided into content theory that focuses on the factors of motivation and process theory that focuses on the process leading to motivation. Because the aim of the present study is to analyze and improve a process that establishes technologies or methods introduced in the PSP course, it is appropriate to use the framework of process theory. In this paper, the structure of a motivation process is represented according to the Organizational Expectancy Model [13] that incorporates factors regarding an environment or organization into the Expectancy Model by Lawler [16], which is a well-known process theory.

Figure 1 illustrates a model based on the Organizational Expectancy Model. It describes the relationship between a personal motivation process included in an execution process of a project, which challenges the introduction of new technologies or methods, and a monitoring and control process of an environment or organization to which a project belongs [15]. In the figure, $Bep$ is the person’s belief concerning the probability (i.e., subjective probability from 0 to 1) that performance $P$ at that level will be achieved if effort $E$ performing at that level is made. $Bpo_i$ is a person’s subjective probability from 0 to 1 that $P$ at the intended level will lead to an outcome $O_i$ ($i \geq 1$), where $i$ is an index to sum up all outcomes. $V_i$ is a valence from $-1$ (very undesirable) to $+1$ (very desirable) that represents the degree of personal emotion or preference for $O_i$, that $P$ leads to. $Bpo_i \cdot V_i$ is summed because there are more than one $O_i$ in general. $Bep \cdot \sum Bpo_i \cdot V_i$ denotes that motivation $M$ is high if the possibility that $E$ leads to $P$ at that level is high ($Bep \gg 0$), the possibility that $P$ leads to $O_i$ is high ($Bpo_i \gg 0$), and $O_i$ is desirable ($V_i \gg 0$).

$E$ is determined by $M$, while $P = E \cdot C \cdot R$, where $C$ denotes a person’s prerequisite ability and $R$ denotes a person’s role perception. Role perception $R$ is a person’s perception of the best way in which effort $E$ leads to performance $P$. $P$ leads to outcomes $O_i$, which are either or both of intrinsic rewards $Rint$, such as a sense of job accomplishment, and extrinsic rewards $Rext$, such as a pay raise or promotion. Job satisfaction $J$ is given as $J = Rint \cdot Rext \cdot Requ$, where $Requ$ denotes a person’s perception of equitable reward. $J$ has effects, such as absenteeism, grievances, and organizational identification. Arrows $X1$, $X2$, and $X3$ denote that personal experiences in the processes of $E \rightarrow P$, $P \rightarrow O_i$, and $O_i \rightarrow J$ will affect $Bep$, $Bpo_i$, and $V_i$, respectively.

Environmental and organizational factors of the monitoring and control process represent external factors that affect the personal motivation process. For example, operations, such as giving an instruction and an advice, by the monitoring and control process affect $R$. Operations issuing written appointments, such as those relating to a pay raise or promotion, affect $Rint$ and $Rext$. Operations announcing a compensation plan or personnel assessment system affect $Requ$. Because $R$ and $Requ$ are directly affected by environmental and organizational factors, the arrows on the both sides from the monitoring and control process are connected to the corresponding factors. On the other hand, the arrow in the middle from the monitoring and control process is connected to the arrows from $P$ to $Rint$ and $Rext$. This is because the relationship between $P$ and rewards is reinforced by environmental and organizational factors.

The levels of $R$ and $P$ are observed by the monitoring and control process, and they will be used in the following
operations to the motivation process.

2.2 State Transition Model

The state of the motivation process involved in the execution process changes as the states of factors of the motivation process are changed by operations of the monitoring and control process. The state transition model of the motivation process [15] treats an individual or organization as a state machine, and formalizes the motivation process using a state set \( \hat{S} \) regarding motivation and an operation set \( \hat{O} \) by the monitoring and control process, where the state transition function of a state machine represents the features or characteristics of an individual or organization.

1. State Set

If the state \( S_F \) of factor \( F \) is discrete, the state set \( \hat{S}_F \) of \( F \) can be described as \( \{ S_{F1}, S_{F2}, \ldots, S_{Fn} \} \). In this paper, it is assumed that the states of factors can be discretized with significant granularity from a motivation point of view of the monitoring and control process. For example, if the state \( S_{\text{Bep}} \) of subjective probability \( \text{Bep} \) can be treated qualitatively as either low or high, the state set of \( \text{Bep} \) can be represented as \{\text{HighBep}, \text{LowBep}\}

Therefore, the state \( S \) of the motivation process can be represented as a tuple \( (S_{F1}, S_{F2}, \ldots, S_{Fn}) \), where \( S_{Fi} \) is the state of factor \( Fi \). Thus, the state set \( \hat{S} \) of the motivation process can be represented as a Cartesian product of the state sets of all factors. Generally, a significant state set of the motivation process is a subset of the total state set. In the following, a significant subset is simply called a state set unless greater clarification is needed.

2. Operation Set

An operation set \( \hat{O} \) denotes a set of inputs to a state machine, and an operation \( O \in \hat{O} \) represents an action, such as giving an instruction, taken by the monitoring and control process. The operation \( O \) affects \( R, R_{ext}, \) and \( Requ \) of the motivation process. Generally, \( \hat{O} \) depends on new technologies or methods being introduced.

3. State Transition and Scenario

The state transition of the motivation process can be represented by a state transition table that describes a Cartesian product of a state set \( \hat{S} \) and an operation set \( \hat{O} \). A motivation process starts from an initial state \( S_0 \) and reaches a final state \( S_n \) via states transited by a series of operations \( O \in \hat{O} \). A time series of states and operations that cause state transitions from an initial state \( S_0 \) to a final state \( S_n \) is called a scenario. In particular, a scenario that results in establishing new technologies or methods is called a successful scenario of establishment, and a scenario that results in failure is called a failure scenario of establishment.

3. State Transition Model of the Motivation Process in the PSP Course

3.1 Overview of the PSP Course

PSP for Engineers, which is an SEI-authorized PSP training course, consists of two course parts: PSP-Planning and PSP-Quality. Each course involves a lecture and exercise on each of four days of the week days, and assigns a report instead of an exercise on the last day. The PSP course offered by Kyutech provides graduate students as elective subjects
with the same content as the PSP for Engineers in accordance with a class schedule. Because available class hours for the PSP course are not enough in a class schedule, students have to do assignments as homework. Therefore, the completion of the PSP course is not easy. However, students are able to develop their skills required for the development of high quality software, and are able to get the certificate of completion by SEI as the same as the PSP for Engineers if all assignments are completed properly. These facts are explained to all students in the guidance of the PSP course so that students of the PSP course are initially motivated well and their intrinsic rewards are clearly defined.

Table 1 is an overview of the PSP course. The columns of the table list the processes for performing assignments, objectives, introduced content, and assignment numbers. In PSP0 and PSP0.1, trainees learn the importance of process discipline and measurement through the introduction of time, size, and defect measurements and process improvement proposals. PSP1 and PSP1.1 introduce size and time estimations, test reports, and task and schedule planning. Report0 establishes a process baseline and improvement goals, and introduces checklists based on the results of the assignments. PSP2 and PSP2.1 introduce quality plan, design and code reviews, design templates, and design verification. Report1 analyzes a trainee’s present state through the whole course, and establishes realistic goals for future improvement.

Table 2. Factors and state sets of the Baseline-STM.

<table>
<thead>
<tr>
<th>Factor</th>
<th>State set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role Perceptron</td>
<td>( R_j )</td>
</tr>
<tr>
<td>Performance</td>
<td>( P_j )</td>
</tr>
<tr>
<td>Intrinsic reward</td>
<td>[IntrinsicRewardGiven, IntrinsicRewardNotGiven]</td>
</tr>
<tr>
<td>Extrinsic reward</td>
<td>[ExtrinsicRewardGiven, ExtrinsicRewardNotGiven]</td>
</tr>
</tbody>
</table>

Table 1. Overview of the PSP course.

<table>
<thead>
<tr>
<th>Course</th>
<th>Process</th>
<th>Objective</th>
<th>Introduced content</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSP0</td>
<td>(1) Process discipline and measurement</td>
<td>(1) Time measurement, defect measurement, and defect type standard</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>PSP0.1</td>
<td>(2) Size measurement, process improvement proposal, and coding/counting standards</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSP1</td>
<td>(2) Estimation and planning</td>
<td>(3) Time estimation, time estimation, and test report</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>PSP1.1</td>
<td>(4) Task planning and schedule planning</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report</td>
<td>(3) Process baseline and improvement goals</td>
<td>(5) Estimation error, time distribution, defect fix time, defect types, defect density, and checklist</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>PSP2</td>
<td>(4) Quality management and design</td>
<td>(6) Quality plan and design/code reviews</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>PSP2.1</td>
<td>(7) Design template</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report</td>
<td>(5) Present data analysis and improvement goals</td>
<td>(8) Designing and state machine</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9) Design verification</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Baseline-STM in the PSP Course

The introduced content in Table 1 represents actions that a trainee should carry out (i.e., the role of a trainee) and the objectives represent goals a trainee should achieve through exercises (i.e., performance). The Baseline-STM is a model that defines the objective, the introduced content, and a pair of a lecture and an assignment as performance \( P \), role perception \( R \), and an operation \( O \), respectively. In this model, a trainee who is introducing the PSP corresponds to the project in Fig. 1. In the following, an assignment represents a pair of a lecture and an assignment for simplicity. Table 2 gives the factors and state sets of the Baseline-STM. For example, factor \( R_1 \) represents the first introduced content in Table 1, that is, \( (1) \) time measurement, defect measurement, and defect type standard. The state set of \( R_1 \) is \{RolePerceived, RoleNotPerceived\}, where RolePerceived indicates that \( R_1 \) leads to an intended level, that is, a trainee can carry out the introduced content as his/her own role, while RoleNotPerceived indicates that \( R_1 \) does not. Similarly, factor \( R_2 \) represents the second introduced content in the table, that is, \( (2) \) size measurement, process improvement proposal, and coding/counting standards. On the other hand, factor \( P_1 \) represents the first objective in Table 1, that is, \( (1) \) process discipline and measurement. The state set of \( P_1 \) is \{PerformanceAccomplished, PerformanceNotAccomplished\}, where PerformanceAccomplished indicates that \( P_1 \) leads to an intended level, that is, the goals of process discipline and measurement are achieved, while PerformanceNotAccomplished indicates that \( P_1 \) does not. The PSP course is designed so that factor \( P_1 \) can leads to PerformanceAccomplished if \( R_1 \) and \( R_2 \) both lead to Role1Perceived and Role2Perceived, respectively.

The successful scenario of establishment starts from \( S_0 \), accomplishes objectives one by one by finishing the introduced content of each assignment appropriately, and finally reaches the final state \( S_f \), where \( S_0 \) is \{UnknownBep, UnknownBpo, UnknownValence, UnknownEffort, UnknownAbility, RoleNotPerceived \((i=1−10)\), PerformanceNotAccomplished \((j=1−5)\), IntrinsicRewardNotGiven, ExtrinsicRewardNotGiven\}.
NotGiven, LowLevelJobSatisfaction) and \( S_{10} \) is (HighBep, HighBpo, LowValence, LowEffort, HighAbility, RolePerceived \( (i=1\sim10) \), Performance/Accomplished \( (j=1\sim5) \), IntrinsicRewardGiven, ExtrinsicRewardGiven, LowLevelJobSatisfaction). In these statements, \( i \) corresponds to the numbers from (1) to (10) in the introduced content column of Table 1 while \( j \) to the numbers from (1) to (5) in the objective column of the table.

This successful scenario of establishment is similar to self-learning because there is no operation such as instruction except for the assignments. In general, however, it is difficult for trainees to achieve sufficient performance without receiving any instruction from the instructors. In fact, all of the trainees do not always complete the PSP course even if the instructors give instructions.

Thus, the Baseline-STM is not detailed enough to be applicable to the practical PSP course. In the following, the Practical-STM precisely refines the Baseline-STM for practical use in improving education.

### 3.3 Factors and State Sets in the PSP Course

PSP0 to PSP2.1 in Table 1 are processes defined for learning about process and intended for the development of small modules after high-level design. They consist of planning, development, and postmortem phases, and the details of each phase depend on an upper process. For example, the development phase of PSP0 consists of detailed-level design, code, compile, and unit test phases. There are usually two following phases where the instructors are able to observe the state of a trainee and take action unless a trainee takes proactive action, such as by asking questions.

1. **Planning phase**

   In the planning phase, a trainee produces a requirements statement for an assignment according to a planning process script, and then produces a conceptual design, estimates the product size and development time, and so on. If a process discipline, such as time measurement, is ignored or there are misunderstandings or errors that result in deviation from the objectives of the PSP course, the following exercises may become meaningless. Therefore, a trainee has to ask the instructors to review a plan. The instructors observe the state of role perceptions according to planning results regarding role perception can be represented. This is because the perception of a role is unknown initially and it cannot be decided after instructions are issued whether a motivation process transits from a state where a role is not perceived to a state where a role is perceived. On the other hand, the factors regarding role perception can be organized into 87 factors by arranging introduced content and if after PSP0.1 as for the introduced content from 1 to 23 in Table 3. The state set of factor \( R_i \) \( (i=1\sim87) \) has a new state element RolePerceptionUnknown so that the unknown state of role perception can be represented. This is because the perception of a role is unknown initially and it cannot be decided after instructions are issued whether a motivation process transits from a state where a role is not perceived to a state where a role is perceived. On the other hand, the factors regarding performance can be organized into 20 factors and classified into two categories. One is \( P_j \) \( (j=1\sim10) \) where objectives are arranged in and after PSP0.1 as for objectives (1) and (2) in Table 3. The state set of \( P_j \) is the same as that of Table 2. The other is \( A_k \) \( (k=1\sim10) \), which represents the completion state of each assignment. The completion state of an assignment is used to decide the suspension of course progress as described in Sect. 3.4. The state set of \( A_k \) can be \{Assignment\NotGiven, Assignment\Given, PlanningOfAssignment\Completed, Assignment\Completed\}, where Assignment\NotGiven indicates an assignment state of an assignment.

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1 The number \( x.y.z \) in Table 3 is the number of key concepts or key skills in PSP BOK Version1.0.
Table 3: Detailed objectives and contents of the PSP0 process.

<table>
<thead>
<tr>
<th>Process discipline</th>
<th>Area</th>
<th>Introduced content</th>
<th>PSP Key Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Report form</td>
<td></td>
<td>(1) Follow the submission order of a report</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) Arrange a complete report</td>
<td></td>
</tr>
<tr>
<td>Program</td>
<td></td>
<td>(3) Produce a workable program</td>
<td></td>
</tr>
<tr>
<td>Test result</td>
<td></td>
<td>(4) Run all test cases</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5) Validate the correctness of test result</td>
<td></td>
</tr>
<tr>
<td>Time recording log</td>
<td>(1.2,7)</td>
<td>(6) Record time data for all steps</td>
<td>2.2.2</td>
</tr>
<tr>
<td>Defect recording log</td>
<td>(1.2,7)</td>
<td>(7) Record all items of defect data</td>
<td>2.2.7</td>
</tr>
<tr>
<td>Plan overview</td>
<td>(1.2,7)</td>
<td>(8) Record planned time</td>
<td>2.1.3</td>
</tr>
<tr>
<td>General</td>
<td>(1.2,6)</td>
<td>(9) Follow a defined process</td>
<td>2.1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(10) Record complete, consistent, accurate process</td>
<td>2.1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(11) Do his/her own work</td>
<td></td>
</tr>
<tr>
<td>Time recording log</td>
<td>(2.2.10)</td>
<td>(12) Follow process steps</td>
<td>2.1.6</td>
</tr>
<tr>
<td>Defect recording log</td>
<td>(2.2.14)</td>
<td>(13) Record time data for each process step</td>
<td>2.2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(14) Record interruption times and reasons</td>
<td>2.2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(15) Record complete and appropriate time data</td>
<td>2.2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16) Record time data in the work was done</td>
<td>2.2.4</td>
</tr>
</tbody>
</table>

Table 4: Factors and state sets of the Practical-STM.

<table>
<thead>
<tr>
<th>Factor (Programming)</th>
<th>Role Perception (P) (j=1~10)</th>
<th>Performance (A) (k=1~10)</th>
<th>Intrinsic reward</th>
<th>Extrinsic reward</th>
<th>Job satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rf ([RolePerceived, RoleNotPerceived, RolePerceptionL:unknown])</td>
<td>PerformanceAccomplished, PerformanceNotAccomplished</td>
<td>IntrinsicRewardGiven, IntrinsicRewardNotGiven</td>
<td>ExtrinsicRewardGiven, ExtrinsicRewardNotGiven</td>
<td>HighLevelJobSatisfaction, LowLevelJobSatisfaction</td>
</tr>
<tr>
<td></td>
<td>Pj ([AssignmentNotGiven, AssignmentGiven, PlanningOfAssignmentCompleted, AssignmentCompleted])</td>
<td>AssignmentNotGiven, AssignmentGiven, PlanningOfAssignmentCompleted, AssignmentCompleted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V ([VeryHighValue, HighValue, LowValue, UnknownValue])</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eff ([VeryHighEffort, HighEffort, LowEffort, UnknownEffort])</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ability ([VeryHighAbility, HighAbility, LowAbility, UnknownAbility])</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bp ([HighBp, LowBp, UnknownBp])</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Bp ([HighBp, LowBp, UnknownBp])</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bep ([VeryHighBep, HighBep, LowBep, UnknownBep])</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V ([VeryHighValue, HighValue, LowValue, UnknownValue])</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eff ([VeryHighEffort, HighEffort, LowEffort, UnknownEffort])</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Ability ([VeryHighAbility, HighAbility, LowAbility, UnknownAbility])</td>
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</tr>
</tbody>
</table>

Trainees require the programming ability to define simple data structures and implement procedures using them. This ability $C$ varies widely among trainees. If $C$ is very high, the performance regarding quality is occasionally accomplished at an early stage, even though related roles are not yet perceived. On the other hand, if $C$ is low, it is difficult for trainees to complete assignments. Therefore, the state set of $C$ can be $\{\text{VeryHighAbility, HighAbility, LowAbility, UnknownAbility}\}$.

Extrinsic rewards for the course are credits assigned to the course and a certificate of completion awarded by SEI and Kyutech, but they are obtained only after the completion of the course. Generally, it is effective to offer extrinsic rewards $R_{ext}$ according to the level of performance $P$ in a timely manner because it will positively affect the personal experience of process $P \rightarrow O_1$, which influences motivation $M$ through $X_2$. In the PSP course, the instructors evaluate a report and grade it “OK”, “Good”, “Very Good”, or “Excellent” for this purpose. Therefore, the state set of $R_{ext}$ is similar to that of the Baseline-STM, but the content of extrinsic rewards is different from that of the Baseline-STM.

Table 5: Operation set of the Practical-STM.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assign A/</td>
<td>Assign assignment $i$ after having a lecture</td>
</tr>
<tr>
<td>(j=1~10)</td>
<td></td>
</tr>
<tr>
<td>Instruct I</td>
<td>Instruct in instruction $i$ corresponding to $R_i$</td>
</tr>
<tr>
<td>(j=1~87)</td>
<td></td>
</tr>
<tr>
<td>Advise</td>
<td>Advise on the contents of work from the software engineering point of view</td>
</tr>
<tr>
<td>Evaluate</td>
<td>Evaluate a report according to performance results</td>
</tr>
<tr>
<td>Suspend</td>
<td>Suspend course progress according to the progress of assignments</td>
</tr>
</tbody>
</table>

The set of operations directed toward a motivation process of a trainee by the instructors consists of $\text{Assign A, Instruct I, Advise, Evaluate, and Suspend}$ as shown in Table 5.

$\text{Assign A}$, is an operation to have a lecture and then assign an assignment $A$ to trainees. $\text{Instruct I}$ is an operation to point out mistakes or insufficiency regarding introduced content as shown in Table 3 and give an instruction $I$ corresponding to $R_i$, such as correction and modification, for process improvement $^\dagger$. On the other hand, $\text{Advise}$ is an operation to give advice on the content of the work product from a software engineering point of view instead of a software process point of view.

$\text{Evaluate}$ is an operation to grade reports according to the performance to provide extrinsic rewards during the PSP course. For example, if zero defect is achieved in a unit test, the report is graded high.

The progress of assignments depends on the trainee. Therefore, if lectures and assignments are given according to an initial class plan, the next assignment may be given

$^\dagger$Unless it is a definite error, only routes to answers that are presumed possibly correct are given, and final decisions are left for trainees as much as possible.
before a trainee completes the previous assignment. This possibly increases the difficulty of the next assignment because the trainee may forget notes or supplements to the assignment or remember them incorrectly. This situation may require greater effort $E$ from such trainees than before by increasing subjective probability $B_{ep}$. However, it is difficult to maintain $E$ at an unreasonably high level for a long time. Thus, $B_{ep}$ decreases in the near future, and this leads to a decrease in motivation $M$. Suspend is an operation to suspend the progress of a class until most trainees complete a current assignment when the progress of a class is not good. It is also necessary to pay attention to trainees who have completed the assignment because the suspension of progress may also decrease $B_{ep}$.

3.5 Practical-STM in the PSP Course

The factors regarding role perception can be organized into 87 factors as described in Sect. 3.3, and each of them can have three states. Figure 2 illustrates a possible state transition of role 17, described as “Record the order of injection and removal of defects correctly”, as an example. Anyway, there are dependencies between some factors regarding role perception. However, there may be no significant effect on the performance even if an instruction is given for each item of a grading checklist rather than taking account of the dependency, when the instructors observe a trainee by checking a report using a grading checklist. Therefore, the state transitions of the factors can be seen as being independent of each other. Figure 3 illustrates a possible state transition of factors regarding a defect recording log that corresponds to a part of objective 2 “Measurement” in Table 3.

The Baseline-STM represents a model where a role is perceived by an assignment as an operation and the performance leads to an intended level without exception. In an actual PSP course, even when instructions are given regarding the problems of process discipline, their effects are not always immediately observed, and the same problems may be observed repeatedly. That is, the performance does not always lead to an intended level even though an assignment is completed. In contrast, performance $P_j$ corresponds to objective 7 “Quality Management” sometimes leads to an intended level even at an early stage of the PSP course while roles regarding process discipline are not yet perceived. Therefore, the state transitions of performance

4. Scenario Patterns and Education Improvement in the PSP Course

4.1 Scenario Patterns

If it is possible to classify the scenarios of motivation processes into typical patterns that are probably reflective of most trainees, a scenario pattern presumed from the observation of a motivation process will assist effective and efficient education. In particular, if it is possible to infer the abandonment of the PSP course by comparing the observation of a motivation process with the patterns, the course completion rate can be improved by appropriate proactive operations that increase motivation.

The following subsections describe typical patterns of the scenarios that are identified by analyzing process data for 55 trainees from the 2007 to 2012 school years. The patterns represent transitions between the major states of motivation processes, where the major states seem important for the effective and efficient management of the PSP course from an instructor point of view.

4.2 Successful Model

The successful model represents a successful scenario of establishment as shown in Fig. 4. The model starts from an initial state $S_0$, and let it reach a state $S_n$ where the performance $P_j$ does not lead to an intended level $Performance/Accomplished$ and role perception $R_i$ leads to $Role/Perception/Unknown$ by $Instruct/1$, operation to
the report of assignment $A_m$ in a postmortem phase. Then, let the model move to a state $S_{m+1}$ where $A_m$ is completed by Evaluate operation to its report. The model then moves to a state $S_{m+2}$ when a new assignment $A_{m+1}$ is given by Assign operation, and then to a state $S_{m+3}$ by Instruct operation after a planning phase. The next state $S_{m+4}$ denotes a state where $R_i$ leads to RolePerceived and thus $P_j$ leads to PerformanceAccomplished by Instruct operation to a report in a postmortem phase while ability $C$ and effort $E$ are HighAbility and HighEffort, respectively. If $P_j$ leads to PerformanceAccomplished, intrinsic reward $R_in$ is given, and then the model moves to a state $S_{m+5}$ by Evaluate operation grading a report high as an extrinsic reward $R_ext$. If $R_ext$ and $R_in$ are given, valence $V$ leads to LowValence by a feedback of $X_3$, and then $E$ leads to LowEffort. If $R_i$ is at an intended level RolePerceived, $P_j$ can still lead to PerformanceAccomplished without HighEffort of $E$. A state $S_{success}$ denotes the final state where the PSP is established.

4.3 Perception Failure Model

The perception failure model represents a failure scenario of establishment. The performance $P_j$ cannot lead to an intended level PerformanceAccomplished because only some roles $R_i$ regarding process discipline or measurement lead to RolePerceived. In this model, states that similar to (HighBep, HighBpo, HighValence, HighEffort, HighAbility, RolePerceived $(i \leq l)$), RolePerceptionUnknown$(j > l)$, PerformanceAccomplished $(j \leq l)$, PerformanceNotAccomplished $(j > l)$, AssignmentCompleted$(k \leq N)$, AssignmentNotGiven $(k > N)$, IntrinsicRewardNotGiven, ExtrinsicRewardNotGiven, LowLevelJobSatisfaction are appeared in a scenario repeatedly as the PSP course progresses. This means that some $R_i$ do not lead to RolePerceived, and thus some $P_j$ do not lead to PerformanceAccomplished even though motivation $M$ is high, that is, HighBep, HighBpo, and HighValence, and effort $E$ is HighEffort and ability $C$ is HighAbility. Because it is difficult to maintain effort $E$ HighEffort long time, subjective probability $Bep$ will decrease eventually and motivation $M$ will decrease. Finally, the scenario reaches the final state (LowBep, HighBpo, HighValence, LowEffort, HighAbility, RolePerceived $(i > l)$), RolePerceptionAccomplished $(j \leq l)$, PerformanceAccomplished $(j > l)$, AssignmentCompleted$(k \leq N)$, AssignmentNotGiven $(k > N)$, IntrinsicRewardNotGiven, ExtrinsicRewardNotGiven, LowLevelJobSatisfaction. This implies that a trainee will certainly abandon the PSP course.

It is necessary to let trainees of this model perceive roles by Instruct operation as soon as possible. If the perception seems to take longer than the time it takes $Bep$ to decrease, it may be effective to provide extrinsic rewards to increase $Bep$ by Advise operation on the contents of a work product from a software engineering point of view. If a class is suspended by Suspend operation for trainees who have not completed an assignment yet, $Bep$ of trainees who have already completed the assignment may decrease and then motivation $M$ may decrease. This failure scenario caused by Suspend operation is different from the perception failure model. However, it is not listed as a typical pattern because such a pattern has not been recognized.

4.4 Very High Ability Model

The very high ability model represents yet another failure scenario of establishment. The performance $P_j$ regarding quality leads to an intended level PerformanceAccomplished even though some roles $R_i$ regarding process discipline or measurement do not yet lead to RolePerceived. Because ability $C$ is VeryHighAbility, $P_j$, such as defect density, is PerformanceAccomplished from the beginning even though effort $E$ is LowEffort and $R_i$ does not lead to RolePerceived. In this

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For simplicity, it is assumed that all roles are perceived and all performances lead to intended levels at the same time.
model, states that similar to (HighBep, HighBpo, HighValence, LowEffort, VeryHighAbility, Rolei/Perceived(i ≤ l), Rolei/PerceptionUnknown(i > l), PerformanceAccomplished(j ≤ J), Performance/NotAccomplished(j > J), Assignmentk/Completed(k ≤ N), Assignmentk/NotGiven(k > N), IntrinsicRewardNotGiven, ExtrinsicRewardNotGiven, LowLevelJobSatisfaction) are appeared in a scenario repeatedly as the PSP course progresses. Subjective probabilities Bep and Bpo, will decrease and motivation M will decrease eventually, because the value in continuing the PSP course cannot be found for such a trainee. Thus, the scenario reaches the final state (LowBep, LowBpo, HighValence, LowEffort, VeryHighAbility, Rolei/Perceived(i ≤ l), Rolei/PerceptionUnknown(i > l), PerformanceAccomplished(j ≤ J), Performance/NotAccomplished(j > J), Assignmentk/Completed(k ≤ N), Assignmentk/NotGiven(k > N), IntrinsicRewardNotGiven, ExtrinsicRewardNotGiven, LowLevelJobSatisfaction). This implies that a trainee will certainly abandon the PSP course.

It may be unnecessary for the trainee to continue the PSP course for personal software development if roles regarding quality measure are perceived. However, the perception of roles regarding process discipline, measurement, estimation, and planning is essential for a trainee to work as a member of a TSP team[19],[20]. It is thus necessary to give Instruct I, operations for helping with the perception of roles that have not been perceived yet and give Advise operation for changing the state of Bpo to HighBpo.

5. Discussion

5.1 Applicability of the Practical-STM

The Practical-STM formalizes the motivation process in the PSP course using a state machine based on the Organizational Expectancy Model. The state of the motivation process is represented as a tuple of the discrete states of factors derived from the introduced content and objectives of the PSP course. The introduced content is mapped to 87 factors regarding role perception while the objectives are mapped to 10 factors regarding performance. The operation set to the motivation process is also defined based on the introduced content and objectives of the PSP course. Traditionally, operations to trainees and decision criteria for taking some operations depend largely on the skills of an individual instructor. In contrast, the Practical-STM allows the formal descriptions of operations and their decision criteria using the discrete states of the motivation process of a trainee. Because of these features, the Practical-STM can be applied to the following applications:

- The decision of effective and efficient operations by presuming a state and a state transition function of the motivation process of a trainee.
- The standardization of the PSP course management and its formal description by systematizing effective and efficient operations according to states and state transition functions of the motivation process of trainees.
- The establishment of the quality evaluation of instructors conducting the PSP course based on the standard of the PSP course management.

Thus, the Practical-STM will contribute the development of new PSP instructors and the support of setting up new PSP courses in an university.

On the other hand, theBaseline-STM assumes that a role is perceived by an assignment and the performance leads to an intended level without exception. The factors and their state sets of the Baseline-STM regarding role perception and performance are not detailed enough to represent the state changes by the operations of instructions, advice, report evaluation, and course postponement that are practically used in the PSP course. Therefore, it is not possible to apply the Baseline-STM to the education improvement of the PSP course.

The scenario of a motivation process represents a pathway from an initial state to a final state of a trainee in the PSP course. A typical pattern of the scenarios represents a model of trainees who behave or are observed similarly in terms of motivation. The patterns of the scenarios are useful for inferring possible transitions of a trainee according to the observations and taking proactive operations from a motivation point of view.

The following are issues in applying the proposed model to an actual PSP course with the aim of improving course management.

5.2 Issues of State Set

The factors of a motivation process can be classified into two categories in terms of the objectivity of state presumption. Effort E, role perception Ri, and performance Pi and Ai can be presumed objectively by evaluating the process data of trainees based on the grading checklists. For example, Ri regarding a review rate can be presumed using product sizes and times spent for reviews in the process data of a trainee, and Pi regarding a defect density can be presumed using product sizes and the number of defects in the process data. On the other hand, it is generally so difficult to objectively presume subjective probabilities Bep and Bpo, valence Vi, ability Ci, rewards Rint and Rext, and job satisfaction J that the presumption of the state of such a factor must depend on the subjective judgment of the instructors. For this reason, the presumption of the state of a trainee may differ between instructors, and the performance may lead to a different level owing to the different operations carried out by the instructors. Therefore, the authors have attempted to presume the states of these factors based on reports as much as possible. For example, Bep can be presumed by

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1Review rate is the number of pages or lines reviewed in an hour.
evaluating the quality of reports. This judgment is based on the assumption that disciplined work will be done and process improvement proposals will be positively proposed if a trainee have belief that performance will be achieved if effort is made. This approach has been effective for the management of the PSP course from the authors’ experiences as the instructors. However, it is important to improve the objectivity of state presumption for the standardization of the course management and the quality management of the instructors of the PSP course. It is a future issue to resolve state presumption methods for subjective factors.

The state of a factor of role perception may not change once from one state to another but rather change step by step. For example, role 21, described as “Record defect types and descriptions consistently”, is perceived step by step while instructions are given for several assignments repeatedly. In such a case, the level of perception should be discretized more precisely by discretizing the states of the factors. For example, the number of mistakes of defect type can be a candidate for segmentation criteria. As the granularity is precise, the state of a factor can be accurately represented, and the trend of the perception level can be observed. It is, however, a future issue to clarify what level of granularity is effective and efficient for instruction improvement by analyzing the process data of the PSP course.

5.3 Issues of Operation Set

Because the PSP for Engineers, which is the basis of the PSP course, is intended for the self-improvement of the software process, the instructions given by the instructors should be limited to process matters in principle. Therefore, the issuing of assignments and instructions according to the grading checklists are significant operations if experienced software engineers in industry take the course.

On the other hand, in a graduate school, at least at the authors’ institute, the trainees of the PSP course do not always have enough experiences in software development, although they have received a fundamental education in information processing, such as programming and software design, at an undergraduate school. Therefore, it is frequently seen that design or coding is inappropriate from a software engineering point of view. The authors’ solution to this problem is that instructors give advice on the contents of the work product from a software engineering point of view because the PSP course is engineering education at a graduate school. It is a unique feature of the educational course at a graduate school that advice from a software engineering point of view, in addition to instructions regarding the software process, is necessary, in contrast to the course for experienced software engineers in industry.

Advice from a software engineering point of view generally depends on the knowledge and skills of trainees. It is difficult to define the content of advice uniformly. How advice contributes to the improvement of the process and performance requires thorough consideration.

5.4 Other Future Issues

This paper presents three patterns of typical scenarios in the PSP course. It seems that subjective probabilities $Bep$ and $Bpo_{i}$, and valence $V_{i}$ differ among trainees at the beginning of the PSP course, because there are differences in not only ability $C$ of programming but also job type or carrier path points of view after graduation. Therefore, it is important to describe the scenarios in more detail and organize the scenarios as patterns for the standardization of the management methods of the PSP course.

Motivation is not a local problem of the PSP course, but a universal problem of practical subjects with a high load of exercises, such as programming or project-based learning (PBL). The proposed modeling approach based on the state transition model is useful in analyzing education methods from a motivation point of view and in establishing effective and efficient management methods. It is a future issue to apply the proposed approach to other practical subjects.

The state transition function of a trainee is determinate in the Practical-STM. However, as discussed in Sect. 5.2, if the granularity of the states of the factors is insufficient, two different state transition functions of trainees may be presumed as the same in an early stage of the PSP course. Moreover, it is natural that other processes or factors outside the model may affect the factors of a motivation process. In such a case, the state transition function appears non-determinate. A non-deterministic function is inconvenient for managing an individual in the PSP course, but a statistical state transition model based on probability is useful for managing a whole class. This is an interesting future issue.

Intrinsic and extrinsic rewards are different between working environment and education environment in general. The Organizational Expectancy Model, where the Practical-STM is based, is intended for the former. Therefore, it is an interesting question whether the model is also applicable to education environment. The proposed approach assumes that the differences between working environment and education environment are only the parameters of the Organizational Expectancy Model, such as the content of rewards, and the fundamental framework of the model can be applied to education environment. The applicability of the Practical-STM to the PSP course in an university indicates that the Organizational Expectancy Model is effective for not only working environment but also education environment. However, it is a future issue whether this result can be extended to the other types of education.

6. Conclusion

This paper proposed the Practical-STM of a motivation process in the PSP course and its application to improving education. The proposed model treats an individual trainee as a state machine, and formalizes a motivation process of a trainee based on the Organizational Expectancy Model. In
this model, a state transition function represents the features or characteristics of a trainee, and inputs to a state machine represent a set of actions taken by the instructors.

The model allows a formal description of the states of a trainee and educational actions of the instructors in the PSP course. From a motivation point of view, the instructors are able to decide effective and efficient actions to take toward a trainee by observing a trainee and presuming a state and state transition function of the trainee. The model is useful for improving the educational effect of the PSP course, and there is the possibility to apply the model to the standardization of the course management and the quality management of the instructors of the PSP course.

The model was applied in the analysis of process data of 55 trainees, and typical patterns, such as a successful scenario of establishment and a failure scenario of establishment, were represented. These patterns are useful for inferring possible transitions of a trainee according to observations and performing proactive operations from a motivation point of view.

The objectivity of the states, the granularity of the state sets, and the relationships between advice and performance must be studied. It is also important to clarify more detailed scenarios as patterns based on the process data. Application to practical subjects with a high-load of exercises, such as the PBL, is also a future issue.

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