Qualitative and Quantitative Analysis of Workflows Based on the UML Activity Diagram and Petri Net

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Abstract: Since business workflows are closely related to enterprise performance, successfule execution of workflow is a critical driving force for strategic advantages of enterprise. Therefore, it is quite essential to customer satisfaction and productivity enhancement that structural errors in workflow instances must be detected and their performance must be evaluated before their enactments.
For a structural verification and performance evaluation of workflows, this paper integrates the strengths of UML activity diagram and Petri net, proposes the mapping scheme from UML activity diagram to Petri net, verify the structural errors of workflow using the reachability tree analysis, and finally predict the workflow performance before its execution using the business process simulation. Through the proposed workflow analysis procedure, workflow modelers in enterprises can analyze the qualitative and quantitative aspects of workflow in an integrated way.

Key-Words: - workflow, UML activity diagram, Petri Net, reachability tree, structural verification, performance evaluation

1 Introduction

In order to survive in the currently competitive and global business environment, most enterprises are struggling to change their existing business processes into more agile, product- and customer-oriented structures**.** Within this environment, a company's business processes must be aligned with corporate strategies and managed properly to attain corporate goals. For the effective business process execution, BPMS (Business Process Management System) [33] and KMS (Knowledge Management System) ([19], [20]) are mostly adopted in enterprises as a strategic driving force for competitiveness and differentiation.

Since a workflow is concerned with the automation of procedures where information and tasks are passed between participants according to the defined set of rules, BPMS is considered a significant enabling technology for the successful implementation of BPR (Business Process Reengineering), or process innovation projects for sustainable competitive advantages. To achieve a desired enterprise performance by using a BPM system, it is required to rapidly execute correct workflow instances for customer satisfaction. Because the enactment of erroneous workflows causes the loss of customer's royalties, prior to workflow execution, the necessity of analyzing the potential errors of workflows in an efficient way is ever increasing. After the structural verification of workflow, it is also neeted that workflow performance must be evaluated before enactment for determining the successfulness of workflow execution.

Van der Aalst and van Hee differentiated between the analysis of the qualitative and quantitative aspects of business workflows [32]. The former mainly concerns the logical correctness of the defined process and can be analyzed typically by Petri net, whereas the latter mainly concerns the performance of the defined process, and can be analyzed typically by simulation method.

Since Petri net can model the dynamic behavior of business processes based on a mathematical formalism, it is widely used for qualitative workflow analysis ([14], [29], [31]). Widely used Petri net techniques for system analysis are the reachability tree and the matrix equation ([26], [27]). The reachablility tree analysis method is quite suitable for workflow analysis because it can detect erroneous states of a workflow such as deadlock and livelock, and can trace the state transitions ([6], [32]). However, in spite of its analysis power, the Petri net model is difficult to understand compared with other diagram models.

UML (Unified Modeling Language) was being rapidly adopted as a de facto object-oriented modeling standard for information system development because of its graphical notation, which is readily understood, and a rich set of semantics for capturing key features of object-oriented systems [25]. Moreover, it was addressed that UML is also appropriate for business process modeling as well as information system modeling by virtue of its expressiveness, user-friendliness, and integration capability with information systems ([11], [23]).

Among UML diagrams, the activity diagram is most suitable for workflow modeling because of the following features: 1) it can describe more easily dynamic behaviors of business process and events triggering the process. 2) It can represent various workflow routing types such as sequential routing, join, split, iteration, and parallel routing suggested by WfMC (Workflow Management Coalition) [35]. However, the activity diagram has limited capability for analyzing business workflows because it suffers from a lack of precise semantics.

The above mentioned characteristics of Petri net and UML activity diagram indicate the possibility of more useful workflow modeling and analysis methods by integrating the ease of modeling with analysis power.

After the qualitative analysis of workflow, quantitative analysis before its enactment such as performance evaluation is promoted to enable the examination and testing of decisions prior to actually making them in the real environment. Businee process simulation (BPS) is a widely used effective tool for detailed quantitative analysis of workflow, due to its ability to evaluate the impact of process changes and new processes in a model environment through the creation of what-if scenarios.

The main objective of this paper is to propose an easy-to-use workflow analysis method integrating qualitative and quantitative aspects for enterprise practitioners by using the mapping scheme from UML activity diagram to classical Petri net. The overall workflow modeling and analysis procedure in this paper proceeds as follows: 1) modeling of workflows by UML activity diagram, 2) transforming a workflow expressed in UML activity diagram into classical Petri net by the proposed mapping scheme, 3) performing reachablility tree analysis of a transformed Petri net for verifying the correctness of business workflow, 4) predicting the workflow performance before its execution using business process simulation.

Through the proposed workflow analysis procedure, workflow modelers in enterprises can analyze the qualitative and quantitative aspects of workflow in an integrated way.

The rest of the paper is organized as follows. Section 2 reviews related works in the area of workflow modeling and analysis using UML activity diagram, Petri net and the combination of both methods. Research works about BPS is also reviewed. Section 3 and 4, the main parts of the paper, describe the mapping scheme and present case scenarios for the validation of the proposed scheme. Section 5 explains the reachability tree analysis method of a transformed classical Petri net for qualitative workflow analysis.

Section 6 describes BPS method for alalyzing the quantitative aspects of worlflow. Finally, the conclusion and suggestions for further research are found in Section 7.

2. Related Works

Since Petri net is based on a strong mathematical formalism and yet allows a graphical representation, it has been mainly considered as a major workflow modeling tool [7] and also an analysis tool for business workflows ([30], [31], [8]). Janssens *et al.* compared several Petri net-based workflow modeling techniques and made a broad outline of desirable future developments [18]. Bosilj-Vuksic *et al.* presented the comparison of IDEF with Petri net for the business process modeling [4].

UML activity diagram has been adopted as one of major modeling tools for business processes. Dumas and ter Hofstede presented the evaluation result of UML activity diagram against a set of workflow patterns and provided insights into the relative strength and weakness of activity diagram [10]. Several works were devoted to the extension of UML activity diagram for the modeling of business processes ([3], [11]).

Eshuis and Wieringa pointed out that UML activity diagram was not intended for workflow modeling [13]. For workflow modeling using activity diagram, they defined semantics for activity diagram, and compared it with various Petri net semantics. However, in the proposed semantics, they did not consider the elements of activity diagram such as object, object flow, and swim lanes. Rodrigues pointed out that activity diagram lacks a well-defined semantics for business processes, and proposed simple semantics by formalizing UML activity diagram using finite state processes [28]. Among various business activities, Donko and Traljic focused on a particular aspect and modeling of the normatively regulated activities of business processes. Particular example of processing claim was described as the formal model [9].

Among research about the transformation of an activity diagram into another format, Mantell proposed the mapping method of an activity diagram into a BPEL4WS (Business Process Execution Language for Web Services) format [22]. One of authors of this paper developed a business process modeling tool based on the transformation method of activity diagram into XPDL (XML Process Definition Language) format file [16]. XPDL is open standard for exchanging workflow definition data by WfMC [36]. White (2004) compared a UML activity diagram with a BPMN Business Process Diagram for the technical availability to represent the workflow patterns, as well as their readability [34]. BPMN BPD was proposed by BPMI [5].

Eshuis and Wieringa proposed a tool which translates an activity diagram into an input format for model checker for the verification of workflow models [12]. Lopez-Grao *et al.* proposed the transformation procedure of an activity diagram into a LGSPN (Labeled Generalized Stochastic Petri Net) for the performance evaluation simulation of software [21]. They, however, excluded the modeling elements of activity diagram such as object, object flow, and swim lanes, for the mapping from an activity diagram to a Petri net. This transformation is not suitable for business workflows because business processes require more modeling semantics such as object flows and activity responsibilities than software processes.

In the area of BPS, April *et al.* suggested the usefulness of simulation for the business process reengineering (BPR) by presenting the case study of a personal claims process at an insurance company [2]. Mevius and Oberweis presented that Petri-net based simulation is useful for the evaluation of process performance [24]. Greasley demonstrated the ability of BPS to incorporate system variability, scenario analysis and a useful display to communicate process performance for BPR [15]. An and Jeng (2005) presented the development of a system dynamics model of business processes for the accurate description of system behavior and what-if analysis [1].

3. The Mapping Scheme of UML Activity Diagram to Petri Net

For the complete workflow modeling and analysis, a workflow model must contain the core entities necessary for defining business processes. The five entities of workflow process definition suggested at the XPDL meta-model [36] and their corresponding elements of UML activity diagram are as follows:

1) Workflow process activity is a work task performed in the course of workflow execution (UML elements: action state, signal receipt, signal sending), and an instantaneous activity that represents the initiation and termination of an activity (UML elements: start point, end point)

2) Activity set is a sub-process that is called from another process, and forms part of the overall process (UML elements: sub-activity state)

3) Transition is a flow from an activity (or a object) to an activity (or a object) (UML elements: transition, object flow), and an operator for routing control (UML elements: decision, sync state)

4) Workflow participant is a resource in an enterprise that can act as a performer of various activities (UML: swim lane)

5) Workflow relevant data are information objects that are used in the execution of a specific task, and workflow applications are invoked software during process execution (UML elements: object)

As in the case of workflow model in a form of UML activity diagram, Petri net-based business process model must contain all entities suggested at the XPDL meta-model. However, classical Petri net primitives don’t provide the semantics sufficiently for representing various business processes. In order to provide sufficient semantics to Petri net models for business workflows, Petri net building block structure called A2P block structure, which is a combination of Petri net primitives, is proposed in this paper.

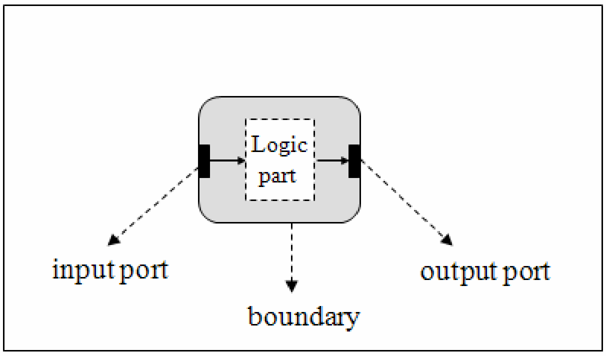

Fig. 1 General A2P block structure

As depicted in Figure 1, general A2P block structure is composed of the following elements:

1) Block boundary: it represents the boundary of an A2P block.

2) Logic part: it consists of Petri net primitives, and describes the behavior of a workflow activity. It starts with ‘transition’ and ends with ‘place’ (except the logic part of ‘source’ activity)

3) Input and output ports: they are used for connecting one A2P block to the other A2P blocks.

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From the view of Petri net, boundary and input/output port elements of A2P block have no effect on the generic structure and properties of Petri net. Specialties of each XPDL entity type is represented by the logic part of an A2P block. Therefore, by using instances derived from general A2P block, each element of a UML activity diagram can be transformed into a Petri net.

In order to map each element of a UML activity diagram to an A2P block, properties of each XPDL entity type are investigated in more detail. The workflow process activity type is further classified to two groups: One is general work task sub-type for a normal activity including signal receipt and sending activity.

The other sub-type is an instantaneous activity that represents the initiation and termination of an activity (i.e., source/sink of workflow process).

The general work task sub-type of UML activity diagram is represented by the A2P block having one input port and two output ports. One of the two output ports is for the transition of an activity, and the other is for the flow of resource availability token. The resource availability token is used for the explicit modeling of a swim lane element which shows the responsibility of a work task.

Since the instantaneous work task sub-type does not need responsibility for a work task, it is mapped to the A2P block having one input port and one output port. Furthermore, source activity sub-type has a different logic part from a sink activity because it should represent the source pool of a specific workflow instance.

Because the activity set type which groups several activities into a sub-process cannot be represented properly by a classical Petri net, the sub-process symbol is newly introduced as one of A2P blocks. It is represented by a rounded rectangle having a bold-line boundary.

However, this additional symbol has no influence upon the generic structure of Petri net.

The transition type is mainly used for the modeling of workflow routing. There are 2 basic routing sub-types (i.e., sequential routing and complex routing) for workflow execution. The sequential routing sub-type such as transition or object flow is transformed into the arc primitive of Petri net. Complex routing sub-type consists of join, split, iteration, and parallel routing. Since complex routing sub-type can be represented by the combination of AND-join, OR-join, AND-split, and OR-split, four additional A2P blocks is added.

The workflow participant type, which represents a resource that can act as a performer of various activities, is mapped to the Petri net token(s) primitive within a place. This type is modeled by swim lane element in UML activity diagram.

Workflow relevant data and workflow applications (WD & WA) type, which require no responsibility for a work task, are mapped to the A2P block having one input port and one output port.

Figure 2 shows a summary of the mapping scheme from UML activity diagram to A2P block for qualitative workflow analysis.

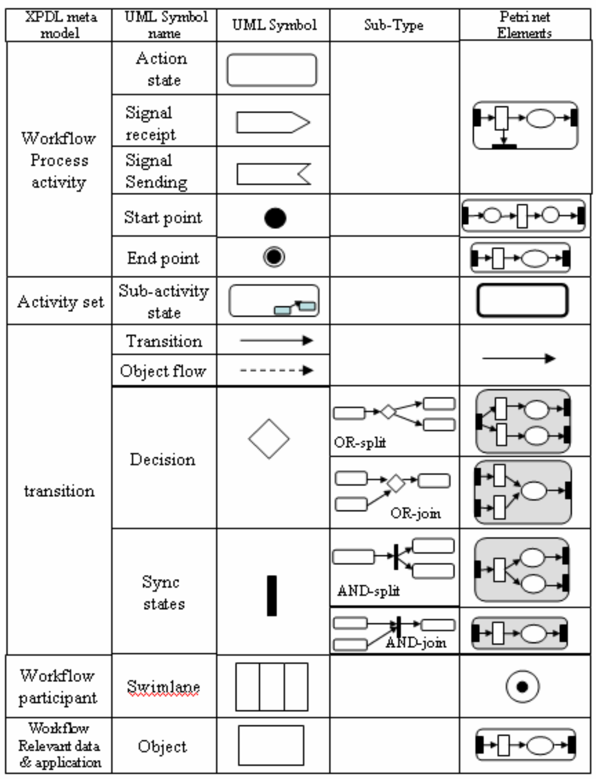

Fig. 2 Mapping scheme from activity diagram to Petri Net

4. Transformation of Workflow Scenarios

To illustrate transformation results through the proposed mapping scheme, three workflow scenarios are presented in this section. For the validation of the proposed mapping scheme, these scenarios cover the wide range of typical business workflows. The case scenarios include various features in real business processes such as complex routings, use of physical or information object as an input or an output for an activity, responsibility of an activity, and sub-processes.

The first business process scenario which was presented in the paper of Van der Aalst, describing a customer complaint handling workflow, is summarized in Table 1 [30]. The main features of the UML activity diagram for this case scenario, depicted in Figure 3, are various routing types such as AND-split, AND-join, OR-split, and OR-join.

Direct Petri net modeling from the case scenario is shown in Figure 4. This Petri net result represents ten transitions (white symbols) for ten general work tasks in the case scenario, and additional five transitions (gray symbols) are included for the workflow routing control. Figure 5 is transformation result of Figure 3 to the Petri net using the proposed mapping scheme. Since this case scenario doesn't specify the responsibility of a workflow participant, A2P building blocks of the resulting Petri net model don't use the output port for the flow of resource availability token. Compared with the direct Petri net modeling, this result requires more transitions and places because of its automatic transformation nature, which uses ten transitions for general work tasks (white building blocks) and additional ten A2P blocks (gray building blocks) for routing control. Reachability tree analysis of two Petri net models results in the same workflow structure (reachability tree analysis is explained in more detail in Section 5). It reveals that the proposed mapping scheme is well-defined and applicable.

The second one, depicted in Figure 6, is an order processing workflow which represents task sequences from order request to product delivery. The main features of this example are the use of information object, object flow, and swim lane showing the responsibility of each work task. The resulting Petri net is depicted in Figure 7, in which a swim lane is transformed into a token within a place, and an information object is mapped to 'WD & WA type' A2P block. Finally, an object flow is mapped to an arc of Petri net.

The last scenario, represented by Van der Aalst and Van Hee, is a machine repair workflow in a factory, described in Table 2 [32]. Figure 8 is the UML activity diagram model of Table 2, of which the main features are the sub-process and complex routing comprised of various combinations of OR-split and OR-join. Transformed Petri net is illustrated in Figure 9, in which the sub-activity state is mapped to the 'activity set type' A2P block.

5. Qualitative Workflow Analysis Using a Transformed Petri Net

After the transformation of UML activity diagram into Petri net, it is necessary to detect the potential structural errors of a transformed workflow model. For ensuring that a business workflow will be successfully executed, a business workflow which is defined in terms of a classical Petri net should satisfy other requirements as well as the requirement of the WF-Net [32].

These are as follows: 1) for any case, a workflow will terminate eventually, and the moment a workflow terminates, there is a token in place 'end' and all the other places are empty. Moreover, there should be no dead tasks; 2) it should be possible to execute an arbitrary task by following the appropriate route through the WF-Net. These two additional requirements correspond to the so-called "soundness" property.

However, because these requirements don't consider the swim lane element of UML activity diagram (i.e. resource availability for an activity), third requirement is introduced newly in this paper. In order to meet the resource availability condition in a usual business environment, the number and the position of tokens representing the responsibility of an activity should not be changed before and after the execution of a business workflow. In particular, in a severe environment of resource limitation, this requirement must be checked before workflow execution.

Whether the transformed Petri net is a WF-Net could be checked easily by examining the structure of workflow. Additional three requirements for the successful execution of a business workflow could be checked by using the reachability tree analysis. The reachability tree analysis of the case scenario one (Figure 5), depicted in Figure 10, reveals 64 total reachable nodes (i.e., states), and among these, there are three terminal nodes (①, ②, ③ in Figure 10).

Table. 1 Workflow scenario-1 for customer complaint handling

1) First, the complaint is registered by executing the task '*register*'.
2) In parallel, a questionnaire is sent to the complainant (task '*send_form*') and the complaint is evaluated (task '*evaluate*').
3) If the customer returns the questionnaire within two weeks, the task '*process_ form*' is executed. If the questionnaire is not returned within two weeks, the result of the questionnaire is discarded (task '*time_out*').
4) Based on the result of the evaluation, the complaint is processed or not. The actual processing of the complaint (task '*process_complaint*') is delayed until the form has been processed.
5) The processing of the complaint is checked via task '*check_ process*'. According to the result of '*check_process*', re-processing may be done again.
6) Finally, task '*archive*' is executed if one condition (the questionnaire has been processed or a time-out has occurred) and the other (the complaint has been evaluated or process has been checked) are satisfied.

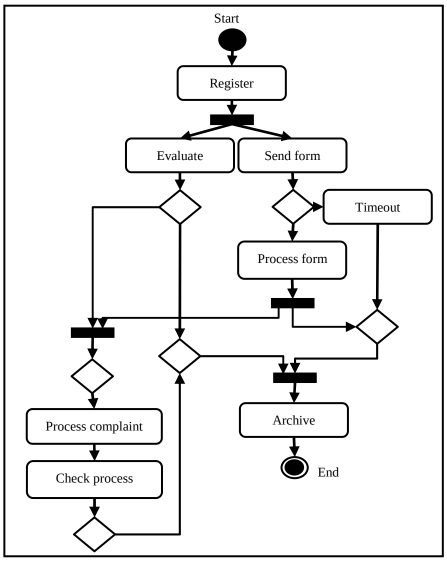

Fig. 3 UML activity diagram for workflow scenario-1

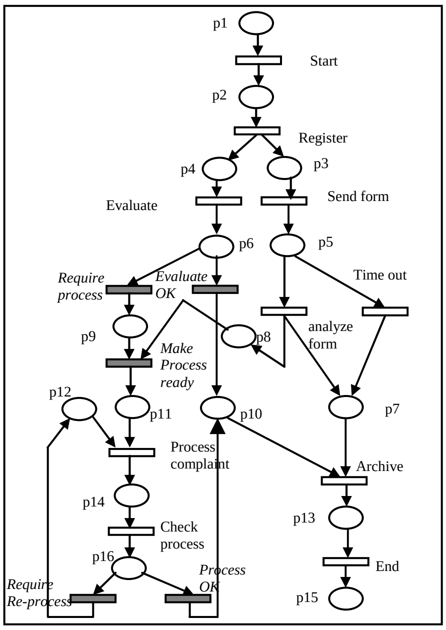

Fig. 4 Petri Net result by direct transformation from scenario-1

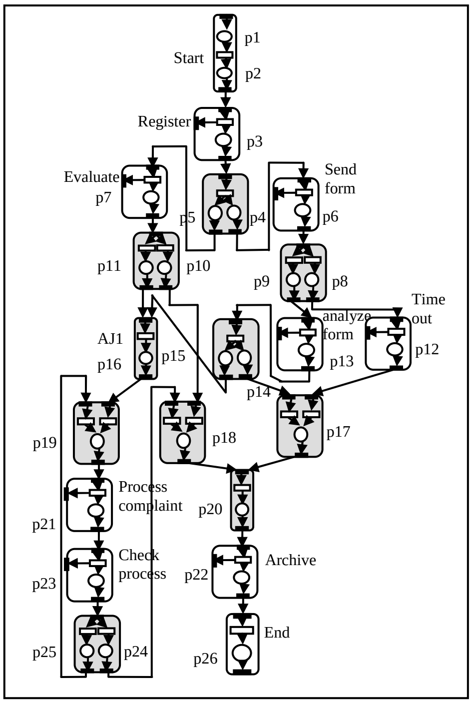

Fig. 5 Petri Net result by proposed mapping scheme

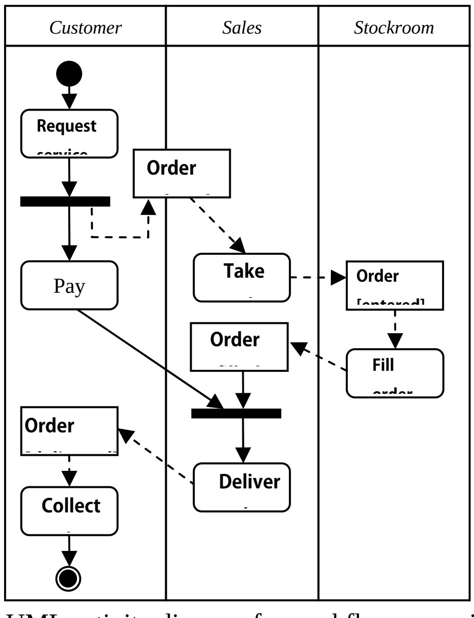

Fig. 6 UML activity diagram for workflow scenario-2

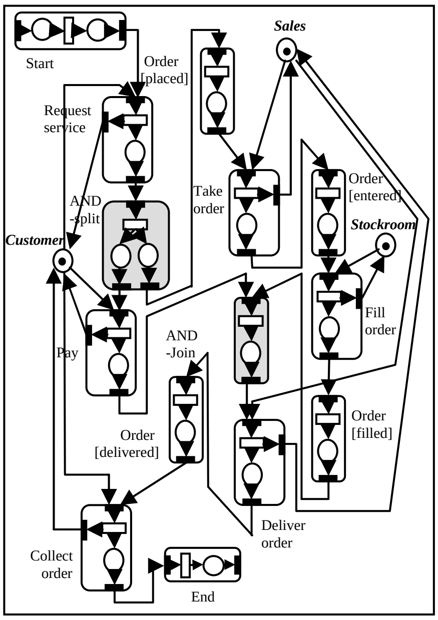

Fig. 7 Petri Net result for workflow scenario-2

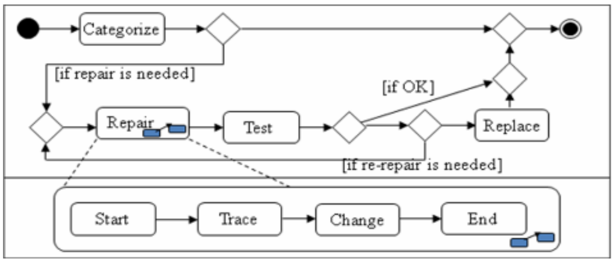

Fig. 8 UML activity diagram of workflow scenario-3

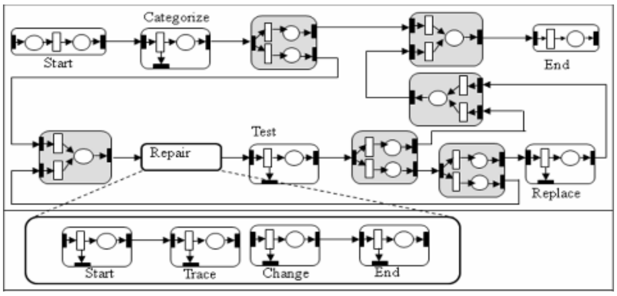

Fig. 9 Petri net result of workflow scenario-3

Table. 2 Workflow scenario-3 for machine repair workflow

1. Every time a fault occurs, it is categorized by the department's mechanic.
2. The fault can often be corrected as it is being categorized.
3. If this is not the case, a repair takes place. Repair activity is a sub-process consisting of the following unit activities: Start-Trace-Change-End.
4. After the repair, a test is carried out.
5. If the fault has been solved, the process is ended.
6. Otherwise, additional activities are required, with two possible results:
   6-1. Further re-repair is needed, or
   6-2.The faulty component must be replaced.

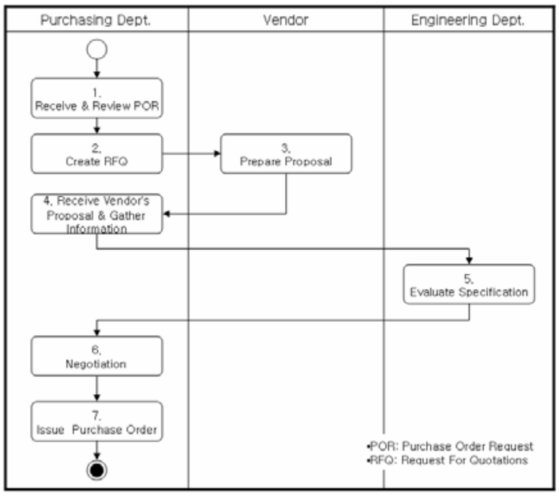

Fig. 11 To-be process of 'placing purchase order'

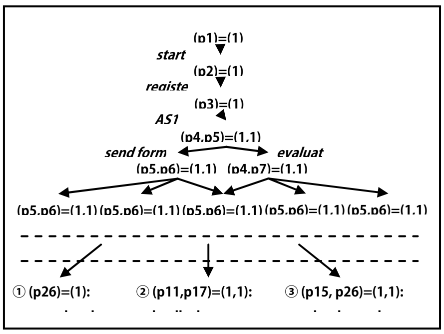

Fig. 10 Reachability tree for workflow scenario-1

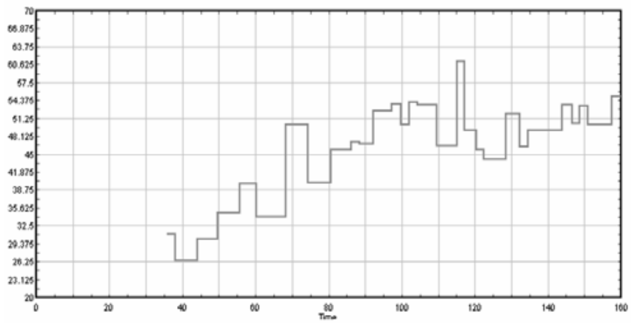

Fig. 12 POR throughput time trend

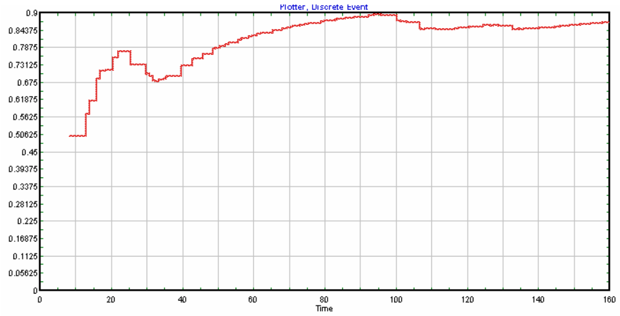

Fig. 13 Labor pool utilization trend

The successful execution condition of a business workflow needs only one terminal node ①, in which there is only one token at 'end' place 'p26'. Since this case has 3 terminal nodes, this workflow can be considered an erroneous workflow. Since the first terminal node ① has no token except 'end' place, it satisfies the soundness property. However, the fact that the second terminal node ② has two places having a token (p11, p17) causes the conflict for the firing of transition 'AJ1' and leads to a deadlock situation. The last terminal node ③ has two places having a token (p15, p26). The existence of a token at place 'p26' implies the successful execution of a workflow, but the additional token at place 'p15' violates the soundness property. As a result, by using the reachability tree analysis of a transformed Petri net, workflow modelers in an enterprise can determine the structural errors of business workflows more thoroughly and in less time.

6. Quantitative Workflow Analysis Using a Business Process Simulation

In the example case scenario of Korean shipbuilding company in this paper, existing as-is workflow of 'placing purchase order' results in high operating costs. Therefore, to-be workflow must be re-designed for improving current workflow. After the structural verification of newly designed workflow, it is necessary to evaluate the performance of workflow before its enactment.

A newly designed to-be workflow is shown Figure 11 in the form of UML activity diagram. This workflow consists of a sequence of seven activities. 1) Receive & Review POR (Purchase Order Request): The purchasing department receives PORs from various departments and reviews them. 2) Create RFQ (Request for Quotations): The purchasing department creates an RFQ, and sends it to a vendor. 3) Prepare Proposal: The vendor reviews the RFQ, then prepares a proposal, and sends it to the purchasing department. 4) Receive the Vendor's Proposal & Gather Information: The purchasing department receives the proposal, gathers related information, prepares a specification, and requests the engineering department to evaluate it. 5) Evaluate Specification: The engineering department evaluates the specification, and sends the evaluation result to the purchasing department. 6) Negotiation: The purchasing department negotiates with the vendor. 7) Issue Purchase Order: After negotiation, the purchasing department issues a purchase order to the vendor.

Activities 1, 2, and 4 in Fig. 11 are executed by a labor pool comprised of 4 workers, while each activity 6 and activity 7 has a dedicated worker. Note that the resource models for the vendor and the engineering department are ignored.

For the performance prediction of the new process, a simulation model is built using Extend tool [17]. One month period (160 hours) is simulated and various performance metrics are measured. The average throughput time for each POR from various departments is 46.4 hours. The trend of POR throughput time is shown in Figure 12. Activity 1, 2, and 4 in Figure 11 is executed by labor pool comprised of 4 workers. And each activity 6 and 7 has a dedicated worker. Average resource utilization of labor pool is 88 %. Labor pool resource utilization trend is shown in Figure 13.

By using the process simulation method, we can predict the performance of the newly designed workflow and easily compare it with that of the as-is process. The results of example case scenario indicate that the average throughput time is reduced by 16 % and the average resource utilization of the labor pool is enhanced by 18 % in the new to-be workflow compared with old as-is workflow.

7. Conclusions and Future Work

It is quite essential to customer satisfaction and productivity enhancement that structural errors in business workflow instances must be detected and corrected before their enactments. After the structural verification of workflow, it is also neeted that workflow performance must be evaluated for determining the successfulness of workflow execution.

In order to model, analyze and evaluate business workflows systematically, this paper integrates the ease of modeling of UML activity diagram with the mathematical formalism of Petri net. For the mapping of UML activity diagram into Petri net, the Petri net building block called an A2P block is proposed. Twelve modeling elements of UML activity diagram are grouped into five types according to the XPDL process definition entities, and are mapped into their corresponding A2P blocks based on their entity attributes. For the validation of the proposed mapping scheme, the transformation results are demonstrated by using three workflow scenarios. The transformed Petri net is used for the reachability tree analysis for the detection of structural errors of business workflows. After the qualitative analysis of workflow, BPS is conducted for alalyzing the quantitative aspects of worlflow. Through the performance evaluation, new workflow can be introduced to enhance the performance of existing workflow.

Through the proposed workflow procedure, workflow modelers in enterprises can analyze the qualitative and quantitative aspects of workflow in an integrated way with less time.

Since 'business workflow' becomes a core competency factor in today's rapidly changing business environment, we need an enterprise-level perspective on the relationships between enterprise performance, business processes and knowledge in a process-centered way. Therefore, the development of enterprise-wide framework intergrating business workflow, performance and knowledge is needed as a future work.

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