A Petri Net-based Workflow Modeling for a Human-centric Collaborative Commerce System

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Collaborative Commerce, Symbolized WorkFlow-nets, WF-nets, Petri Nets, Workflow Modeling and Processes.

ABSTRACT
During the last decade, collaborative commerce and human-centric systems concepts have been applied in several enterprise information systems. Many researchers have studied, developed and proposed architectures for such systems. In order to validate and verify the systems' architectures, researchers use various types of modeling and analysis techniques available. One well-recognized technique is WorkFlow-nets (WF-nets), which is based on Petri Nets. WF-nets focus on control flow and provide a powerful analysis mechanism to verify the correctness of workflow procedures. This paper discusses a human centered collaborative system (HCCS) that has a Web-based architecture and pays special attention to collaboration and human-centric issues. The system is modeled using Petri nets and workflow nets. The paper then introduces Symbolized workflow-nets (SWF-nets) which employ symbolized places, transitions and arcs to illustrate the complicated processes more effectively. Next, it presents an example, a college admission system, as a case study that can be implemented in the HCCS environment. We model the admission processes using SWF-nets to illustrate the validation and verification of the HCCS architecture.

1. INTRODUCTION

Lately, organizations in distributed environments have become more dynamic than ever. Information technologies (IT) have developed rapidly and information systems play a major role in such environments. Other noticeable renovations in the IT areas are those associated with Internet-based systems, such as electronic commerce (e-Commerce) systems. Working in distributed and collaborative environments with Internet-based systems introduces the subject of collaborative commerce (c-Commerce). C-Commerce systems support dynamic collaboration among individuals and organizations to enhance their overall performance. They also harness all organization's information to provide personalized access to all participants in a given organization (Chen 2000; Kim and Smari 2005; Thuraisingham et. al. 2002).

The aforementioned changes make individuals and organizations more competitive, and their tasks more complicated. Today, organizations seek to achieve the goals through distributed and specialized resources. At the same time, they want their systems to support the execution of individual tasks and manage the flow of work (Georgakopoulos, et. al. 1995; Yi et. al., 2004). In order to consolidate and automate such information resources and tasks in an organization, workflow technologies provide an appropriate platform to achieve that (Sadiq 2005).

A workflow is a partially or a wholly automated process which contains tasks, data and resources. Workflow management is a technology that includes the concepts, techniques, and tools to support the management of workflow processes (Abbott and Sarin 1994; Smari et. al., 2006). Many individuals and organizations have developed their own workflow management systems (WFMS), to support their projects and processes and also to contribute to the workflow management technology markets (Jablonski and Bussler 1996). WFMS is a system that defines, creates and manages the execution of workflows through the use of software that is able to interpret the process definition, interact with workflow participants, and invoke the use of IT tools and applications. The main reason for using a WFMS is to support the definition, execution, and control of processes (WfMC 1999).

Once an organization has developed a framework of a system, it should use some modeling techniques to verify that such a framework will do the job intended before implementing it. Many researchers have recognized Petri nets' (PN) effectiveness as a modeling tool for workflow systems. Graphical representation and self-documented characteristics are the main advantages of using Petri nets to support the verification procedure of system processes. Further details of Petri nets will be discussed in the next section.

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This paper's main objectives are to validate and analyze a previously introduced c-Commerce architecture as well as propose an abstract, the Symbolized WF-nets (SWF-nets), which is a modification of the Petri net-based workflow nets approach. Basically, SWF-nets are WF-nets with symbolic places, transitions and arcs to enable easier and more effective visualization of the whole process. We first establish some definitions of PNs, WF-nets, and SWF-nets. Then, we develop the suitable case study, the college admission system scenario, and model the processes in such a system using SWF-nets to determine the validity of both the proposed architecture and the SWF-nets approach.

This paper is organized as follows. The next section introduces this paper's background issues and concerns. It also describes the main terminologies used in Human centered c-Commerce system, Petri nets, and WF-nets. We outline the proposed abstract, SWF-nets, their role and properties in Section 3. In Section 4, we present SWF-nets characteristics and analysis. This will be followed in Section 5 by a case study, the college admission system, and the details of the HCCS architecture's components that will relate to the case study. Section 6 shows the system model of the case study using SWF-nets. Finally, the paper offers some conclusions and future perspectives in Section 7.

2. BACKGROUND AND TERMINOLOGY

Mainly, this section divides into two sub-sections. First, Human-centered Collaborative Commerce System (HCCS) which introduced an architectural framework for c-Commerce that integrates human factors and aspects with e-Commerce (Kim and Smari 2005) is discussed. The next section talks about Petri net which is a modeling language for representation and analysis of systems (Peterson 1977), and WorkFlow nets (WF-nets) which is Petri nets-based modeling analysis techniques (Aalst 1998).

2.1 Human Centered Collaborative Commerce System

Recently, more organizations have been configured as distributed sub-organizations. Individual users of a sub-organization seek better and faster services to access and share information with user-friendly environments. In order to provide seamless collaboration among these participants and systems, an eminent framework for human centered collaborative system is essential. The human-centered decision making system (HUDS) (Kim et. al., 2004) with capabilities for knowledge management was developed to fulfill these demands. The HUDS architecture can be employed in different situations, e.g., information grid environment (Smari et. al., 2005a), collaborative engineering design platform (Smari et. al., 2005b) and c-Commerce system (Kim and Smari 2005).

Figure 1 illustrates the proposed architecture of the HCCS (Kim and Smari 2005) which is one of the extension works of the HUDS architecture. The HCCS has three managers: display manager, user manager, and information manager. The display manager takes care of controlling input and output devices of a virtual place and the Webpage. The user manager controls the use of system and network resources while information manager manages information in the HCCS.

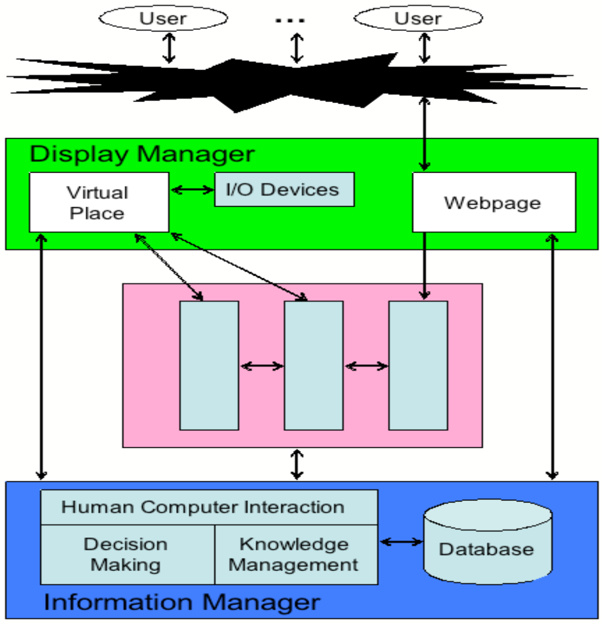

Figure 1: Proposed Architecture of the HCCS

Users of an organization, such as department members, managers and directors, as well as others, such as customers, applicants and partners, can access to the virtual place through the Websites. On the Websites, there are different types of information of the organization, and anyone can browse the sites anytime and anywhere. Existing or new authorized users can access to the virtual place after they provide their personal information and get the permissions. The information of c-Commerce and the HCCS architecture (Kim and Smari 2005), architectural framework for each module of the HCCS (Kim et. al., 2006a), and an extended architecture, its security features and access control techniques (Kim et. al., 2006b) can be found in different articles.

2.2 Petri Nets and Workflow Nets

The classical Petri net is a bipartite directed graph with two types of nodes: places, i.e., graphically represented by circles, and transitions, i.e., graphically represented by rectangles. The nodes are connected via directed arcs which mean arcs, also called edges, are either from a place to a transition or from a transition to a place. At any given time a place contains zero or more tokens, i.e., graphically represented by black dots (Peterson 1977; Murata 1989). A Petri net can be formally defined as the following (Aalst 1998; Dong and Chen 2005; Murata 1989):

Definition 1: A Petri net is a triple (P, T, F), where P is a finite set of places, i.e., P = $\{p_1, p_2, p_3, \dots, p_m\}$, T is a finite set of transitions, i.e., T = $\{t_1, t_2, t_3, \dots, t_n\}$, and F is a set of arcs (flow relation), i.e., $F \cap (P \cap T) \cup (T \cap P)$.

A place *p* is called an input place of a transition *t* if and only if there exists a directed arc from *p* to *t*, and •*t* denotes the set of input places for a transition *t*. A place *p* is called an output place of transition *t* if and only if there exists a directed arc from *t* to *p*, and *t*• denotes the set of output places for a transition *t*. Similar notations can be used for •*p* and *p*•, where they denotes the sets of transition sharing *p* as an input places and output places, respectively.

A major strength of Petri nets is their support for analysis of many behavioral properties which depend on initial state (Murata 1989). Reachability, Boundness, Liveness, and Strongly connected are useful properties when we need to study the dynamic characteristic of a system modeled by Petri net (Aalst 1998; Murata 1989; Yi et. al., 2004).

Definition 2: Given a Petri net (P, T, F), and states M_1, M_2, …, M_n, a state M_n is called reachable from M_1 if and only if there is a firing sequence of transitions, t_1, t_2, … , t_{n-1}, that transforms M_1 to M_n.

Definition 3: A Petri net is bounded, if and only if for every reachable state and every place *p*, the number of tokens in *p* is less than a natural number.

Definition 4: A Petri net is live, if and only if for every reachable state and every transition *t*, there is a state M_n reachable from M_m that enables *t*

Definition 5: A Petri net is strongly connected, if only if for every pair of places, *p*, and transitions, *t*, there is a directed path from *p* to *t*.

A workflow process definition can be modeled by a Petri net, which is called a WorkFlow net (WF-net) (Aalst 1998). A WF-net satisfies two requirements; first, there should be a source place *i* and a sink place *o*; second, every transition *t* and place *p* should be located on a path from place *i* to *o*. Formal definition is addressed in Definition 6.

Definition 6: A Petri net is a WF-net, if and only if, it satisfies the following two conditions; first, there should be one input (*i*) and one output (*o*) places, i.e., •*i* = {}, and *o*•= {}; second, when a transition t_i is added to Petri net, the transition t_i connects place *o* with *i*, i.e, •t_i ={*o*} and t_i• ={*i*}.

3. SYMBOLIZED WORKFLOW NETS

The WF-nets are powerful modeling tools. However, when we consider the complex sequences of work, the modeling of the all sequences of the system using WF-nets are not easy and become obscure. Another drawback is that it is difficult to do performance analysis. To cover some of drawbacks of the WF-nets, Normalized WF-nets (NWF-nets) were introduced (Li and Song 2005). The NWF-nets include some additional graphical components to overcome those difficulties. But, the NWF-nets can only be performed better in case of the simple processes. NWF-nets are also failed to consider the complicated processes.

We have developed a symbolic WF-nets called Symbolized WorkFlow nets (SWF-nets), to emphasis on graphical properties of the Petri net. The SWF-nets are facilitating the easy communication between system processes, process designers and system users.

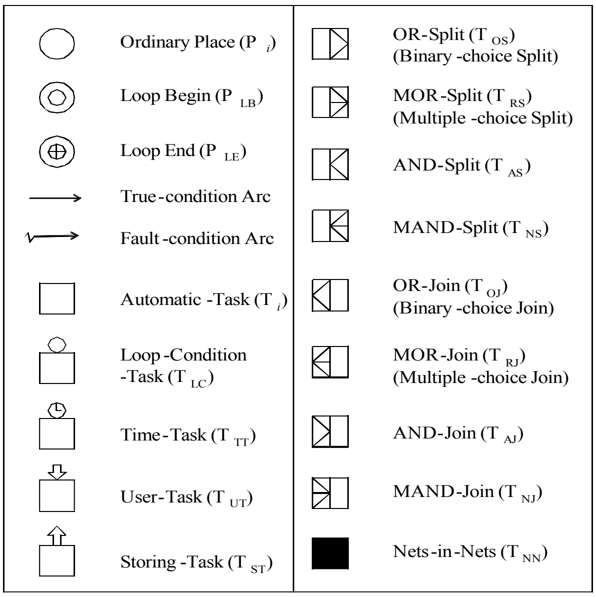

Figure 2: Components of SWF-nets

Figures 2 and 3 illustrate the components and some examples of SWF-nets, respectively. There are three types of places, two types of arcs, and 14 types of tasks: 5 behavioral tasks, 8 routing-involved tasks, and 1 nets-in-nets task.

Ordinary places, True-condition Arcs, and Automatic-tasks have the same meanings as those associated with places, arcs, and transitions in Petri nets. OR-Split and OR-Join, MOR-Split and MOR-Join, and AND-Split and AND-Join have to be used in pair, as shown in Figure 3 (i) and (ii). There are Loop Begin and Loop End for loop structure. The loop structure should be used with loop-condition-task to avoid any livelock which will be discussed in the next section. Figure 3 (iii) illustrates the loop example, i.e., if t_{LC} is true, then it goes to t_3, otherwise it will be looping until the loop condition t_{LC} is satisfied. True-condition Arc and Fault-condition Arc should be used with either the loop structure or the binary-choice split, as depicted in Figure 3 (i) and (iii). Figure 3 (iv) shows the user-task, time-task, and storing-task. Task t_{UT} is executed by a user; t_{TT} is executed at a predefined time; and executing t_{ST} results in storing information into a certain database. The Nets-in-Nets indicates nested nets inside the task, as will be shown in Figure 7.

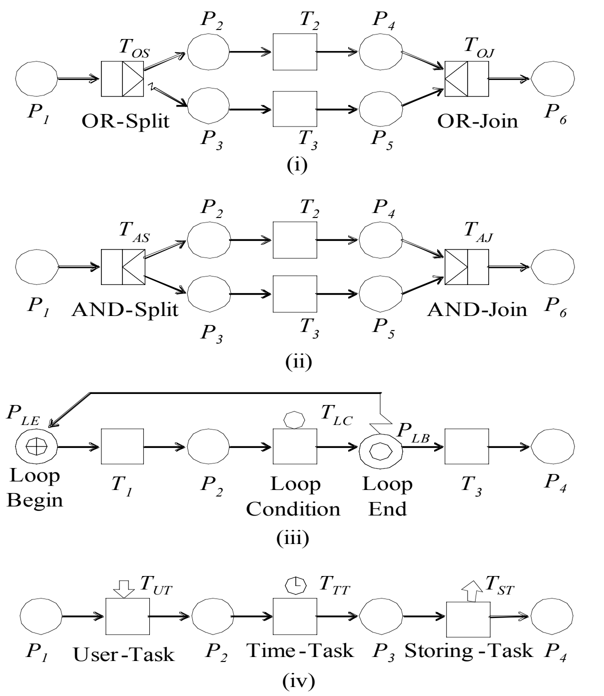

Figure 3: Examples of Using Components of SWF-nets

Table 1: SWF-net Expression for Figure 3

Example	Formulized Expression
(i)	$P_1T_{OS}(P_2T_2P_4 \cap P_3T_3P_5)T_{OJ}P_6$
(ii)	$P_1T_{AS}(P_2T_2P_4 \cap P_3T_3P_5)T_{AJ}P_6$
(iii)	$P_{LE}T_1P_2T_{LC}P_{LB}T_3P_4$
(iv)	$P_1T_{UT}P_2T_{TT}P_3T_{ST}P_4$

Three operators can be used to formulize the SWF-nets. T_1T_2 represents the sequence routing which means that task 1 (T_1) should be executed before task 2 (T_2). $T_3 \cap T_4$ represents the choice routing which means that either task 3 (T_3) or task 4 (T_4) should be executed not both. $T_5 \cap T_6$ represents the parallel routing which means that both task 5 (T_5) and task 6 (T_6) should be executed parallel. Table 1 shows the SWF-net expressions for the four examples depicted in Figure 3.

4. ANALYSIS OF SWF-NETS

Three major workflow analysis methods are identified by Aalst (1998): verification, validation, and performance analysis. Verification examines the correctness of the workflow process definitions while validation determines if the workflow will behave as intended. A performance analysis technique requires more advanced methods, such as simulations. In this paper, we use Petri nets as a tool for verification and validation of the proposed workflow.

The lack of verification and validation of a workflow often results in runtime errors, such as deadlock and livelock. (Aalst 1998). A deadlock happens when a workflow gets stuck in a task, as a livelock occurs when a workflow has trapped in an infinite loop. As long as a workflow can be represented and executed without these errors, we can say that the workflow is well defined. In order to provide the evidence of being well-defined nets and capabilities of describing the system behavior, there is the need to prove the workflow is sound.

4.1 Soundness of SWF-nets

If a workflow is reachable, boundness, liveness and strongly connected, there should be no deadlock and livelock in any route, and the moment the flow ends there is a token in place *o* which is the output place. These constraints correspond to soundness property. Definition of the soundness in a workflow is defined by Aalst and Hofstede (2000).

Definition 7: A workflow is sound if and only if, it satisfies the following three conditions; first, for every state M reachable from state *i*, there exists a firing sequence leading from state M to state *o*; second, state o is the only state reachable from state *i* with at least one token in place *o*; third, there are no dead transitions in the workflow.

Theorem 1. SWF-nets are the subset of Petri-nets.
Proof. The WF-nets are subset of Petri nets (by Definition 1) and the SWF-nets satisfy the WF-nets definition (by Definition 6). Therefore, SWF-nets are the subset of Petri-nets.

Theorem 2. SWF-nets are sound.
Proof. SWF-nets are subset of the Petri-nets and SWF-nets are reachable (Definition 2), bounded (Definition 3), live (Definition 4), and strongly connected (Definition 5). Therefore, the SWF-nets are sound (Definition 7).

These proofs allow us to use standard Petri net analysis tools to verify the correctness of the SWF-nets (Aalst et. al., 2000).

4.2 Comparisons

SWF-nets are subsets of WF-nets and satisfy most of properties of WF-nets. WF-nets have some advantages and disadvantages compared to other workflow nets.

First, SWF-nets structure gives a clearer understanding than other workflow nets. Four pairs of routing construction features and a loop-condition-task, shown in Figure 2, provide no structure faults, such as livelock, deadlock, or dead-task. Furthermore, symbolized places, arcs, transitions, and net-in-net representations provide apparent view of processes, i.e., easy to debug, change, and modify, as well as hierarchical view for complicated processes, i.e., top-down illustrations, as shown in Figure 7. Lastly, once processes are constructed by SWF-nets, they also can be formulized using three operators. The formulized expression provides the whole workflow at a glance.

As a disadvantage of using SWF-nets, the representation of processes is a bit longer than others since SWF-nets have more detailed symbolized components than others.

5. A CASE STUDY: COLLEGE ADMISSION SYSTEM AND PROCESSES

Graduate school admission process is complicated process. Many users are involved, e.g., applicants, reviewers, and decision makers, and many tasks have to be done in sequence, e.g., application form first, other supporting documents, and reviewing. We used the HCCS architecture to model the college admission processes.

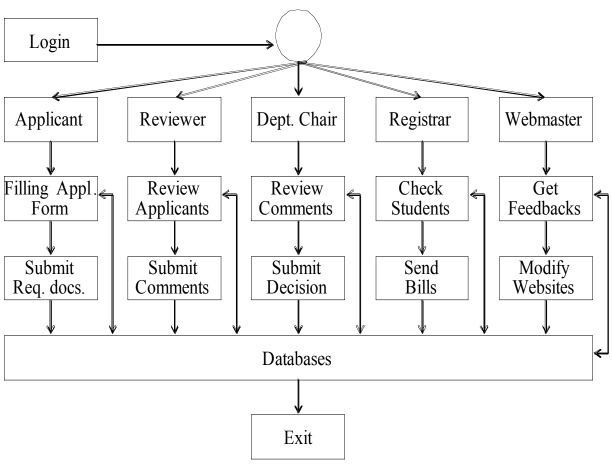

Figure 4: Possible Users and Procedures

Generally, there will be school Websites that anyone can browse. If anyone wants to apply the school, one needs to create an account and proceeds to the next steps, e.g., filling in the application form, uploading supported documents, and checking the status of application processes. Later, these applicants who submitted all required materials will be reviewed by reviewers to decide the acceptance. There are also other possible users; reviewer reviews applicants' files and make comments; department chair examines reviewers' comments and make decisions; registrar verifies admitted students and sends bills; webmaster checks Websites and update information. Figure 4 shows a simple workflow to illustrate procedures of each user's possible activity.

Based on possible users, four user levels are identified, as shown in Table 2, and a role hierarchy is generated as shown in Figure 5, for the case study.

Table 2: User Levels and Possible User Actions

User Level	T	Web Sites	Virt. Place	Possible User Action
UL 0	N	Y	N	Anyone can browse school Websites and get information about the school.
UL 1	R	Y	L	Applicants can submit the application and upload supporting documents.
UL 2	R	Y	Y	Reviewers can review applications, and access to supporting files.
UL 3	A	Y	Y	Department chair can access reviewers' comments, and make decisions.

User level 0 (UL 0) contains normal (N) users, e.g., users who want to browse the school Websites and no access to virtual places, e.g., application Website, etc. User levels 1 and 2 include registered (R) users, e.g., applicants, reviewers, and they can access to virtual places but UL 1 has limited access privileges to it. UL 3 can be assigned to the department chair to give full access privileges.

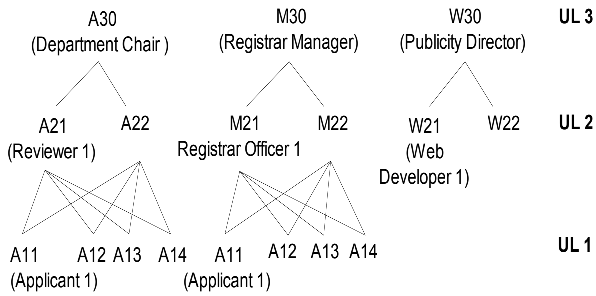

Figure 5: Role Hierarchy with the User Levels

Expanded procedures of admission processes are shown in Figure 6. Depending on the user level a user can be directed to the right place. This workflow still shows brief activities of each user level. Detailed explanations of some security features, i.e., session assignment, RGT assignment, UAM setting, can be found in the previous article (Kim et. al 2006b).

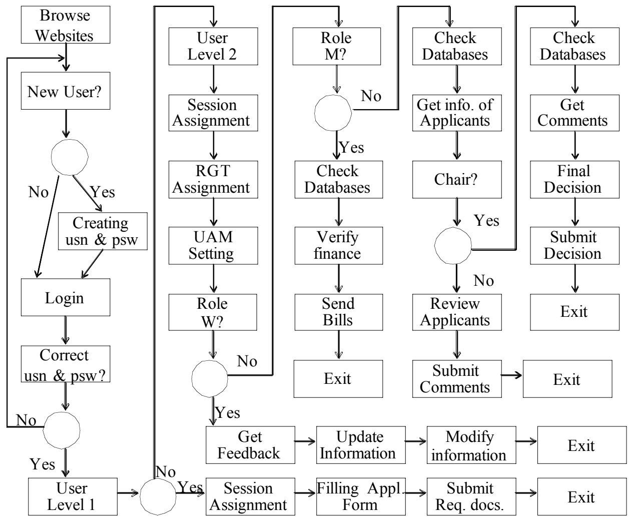

Figure 6: Detailed Procedure for Admission Processes

6. PROCESSES MODELING USING SWF-NETS

Figure 7 shows the whole admission process which consists of three nets-in-nets processes: login, applying and reviewing processes (shown in Figures 8, 9 and 10, respectively). The nets-in-nets representation in the SWF-nets is one of the main advantages. The top-down zooming view approach gives a clear understanding of the whole process, i.e., view 1, as well as the detail of a portion of the process, i.e., view 4. Figure 7 illustrates the top-down zooming view approach of the admission process. There are three zooming views to examine tasks of the department chair, i.e., reviewing process (View 2), reviewing issues (View 3), and decision making (View 4). For example, from the View 1, we can highlight the whole process as follows: depending on the login process, a user will be categorized by three levels and the user will follow the corresponding route, and from the View 4, we can observe what a department chair needs to do.

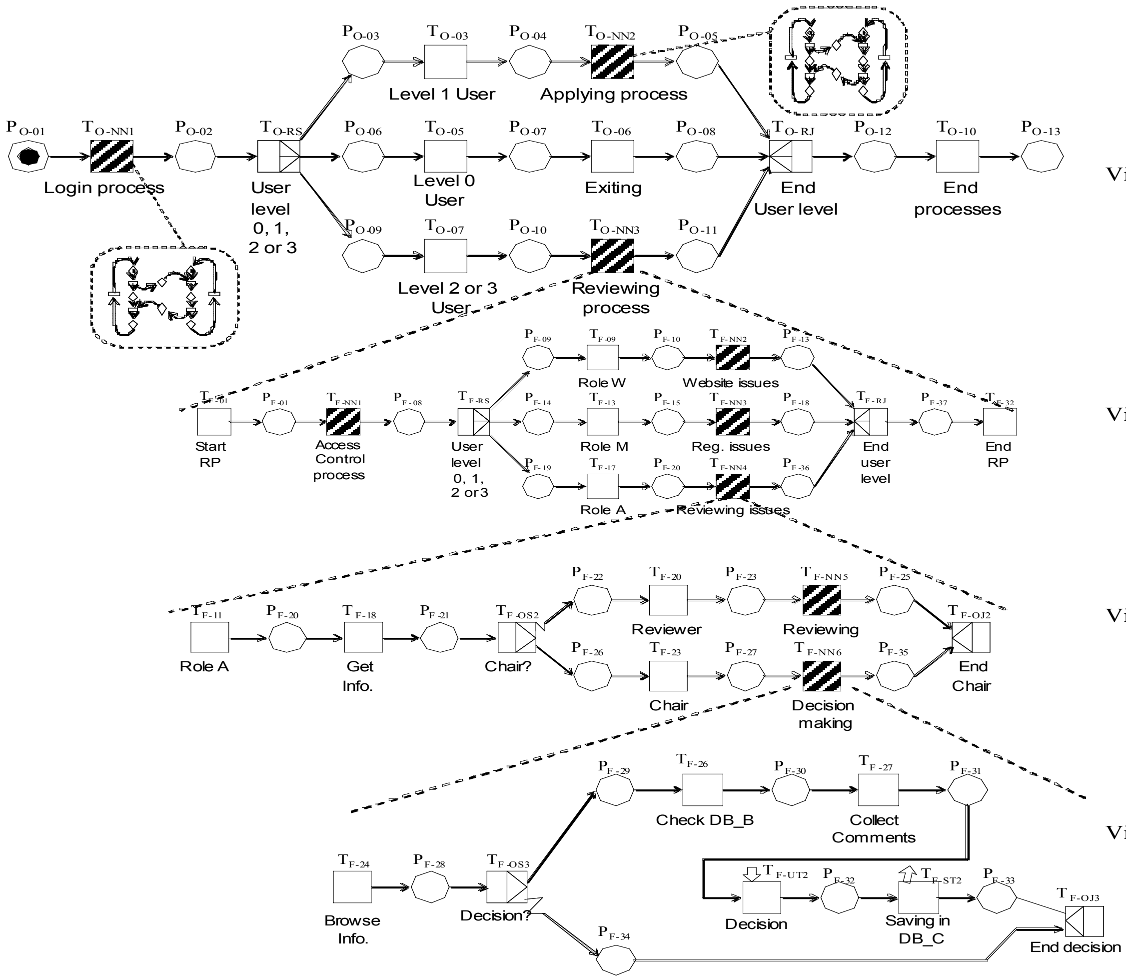

Figure 7: The Admission Process with Nets-in-nets

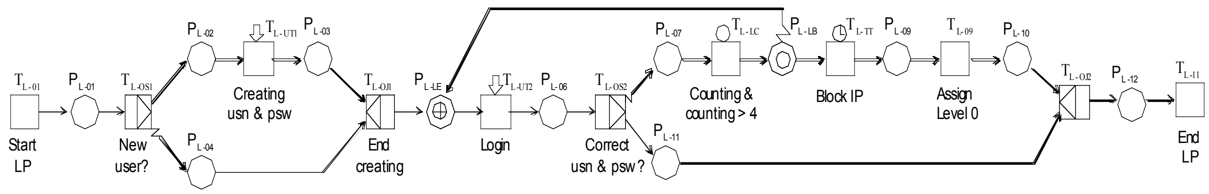

Figure 8: Login Process

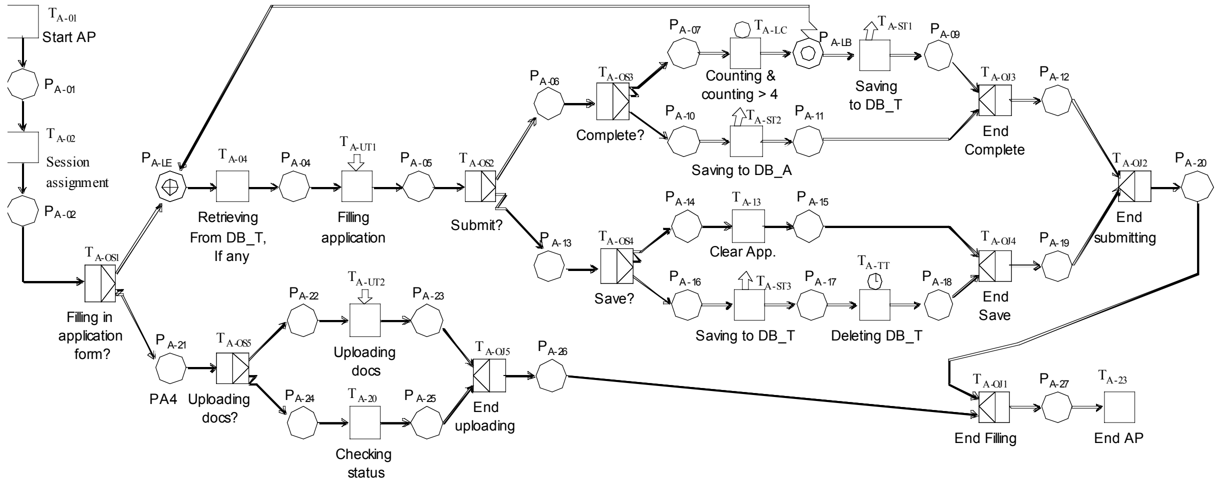

Figure 9: Applying Process

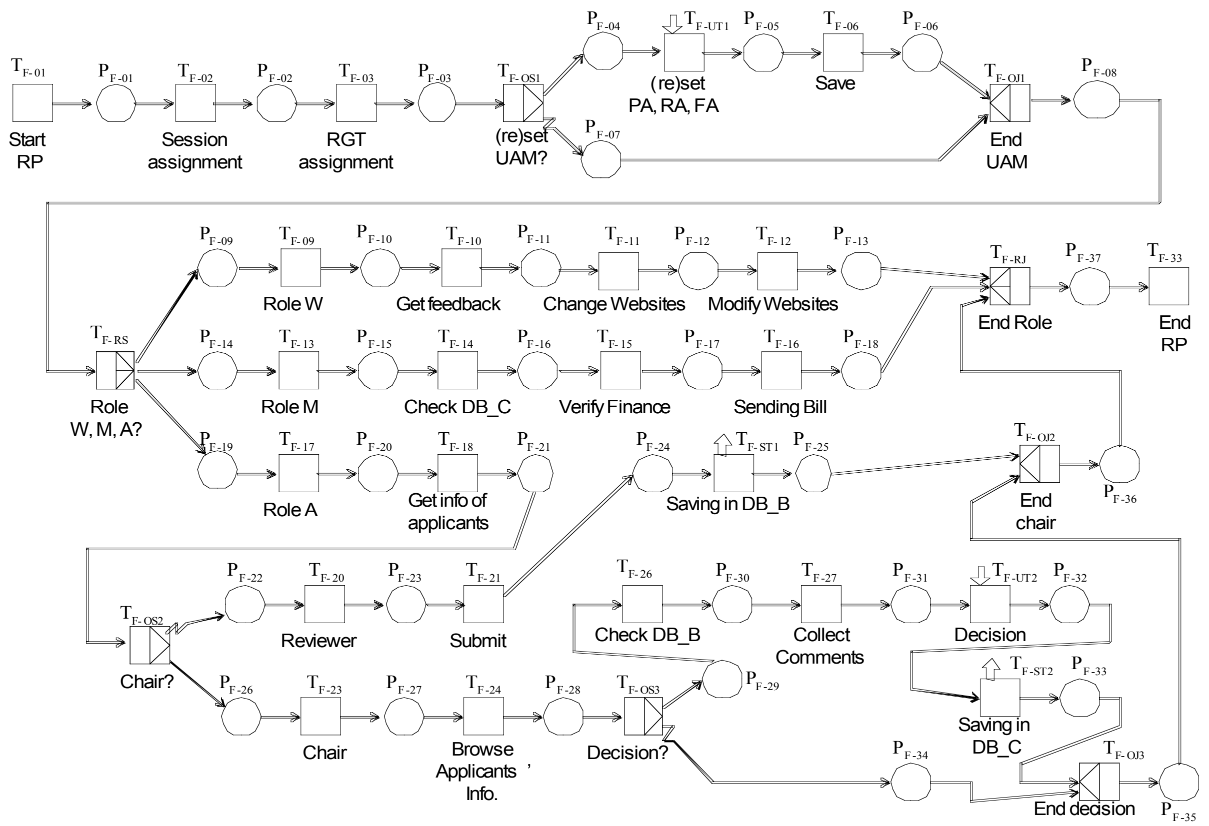

Figure 10: Reviewing Process

Login process is shown in Figure 8. First, it verifies whether a user is the new user which requires creating a username and a password, or not. Once the user enters his or her login information, the system checks the correctness of login information. If it is correct, then login process is ended. If it is not correct, the user can try three more times. After the fourth time of failing to provide the right login information, the system blocks the IP address for a certain periods of time, and at the same time, the user is assigned 'level 0 user' and exited from the system. This method is used many financial institutions to prevent the system from abusing by phony users.

Applying process is shown in Figure 9. Based on the security features of the HCCS architecture, a user will be assigned a session. Then, there are three choices for the user: filling in the online application form, uploading supporting documents, or checking the status of the process. In case of filling in the online application, system checks the temporary database (DB_T) to see the user is whether the returning user or not. If the user completes the application form the system saves the form in the database (DB_A) which will be available to the reviewers later. If the user wants to quick this time the system will save current form in the temporary database (DB_T) which will be retrieved whenever the user comes back later. However, if the user is not coming back within a certain period of time, the system will delete the temporary database. Other cases are to upload the supporting documents, e.g., test scores, letters and so on, and to check the status of application process.

Lastly, the reviewing process is shown in Figure 10. Places from P_{F-01} to P_{F-08} are doing the session and RGT assignments and setting or resetting the User Analysis Module (Kim et. al 2006b). Then, depending on the user's role, the user will do the corresponding work, e.g., Web design department people and registrar office people will go through places from P_{F-09} to P_{F-13}, and places from P_{F-14} to P_{F-18}, respectively. A reviewer can review the applicants and submit their comments. The chair can submit the final decision once reviewers leave their comments in the DB_B.

6.1 Formulized Expressions of Case Study

The whole admission process can be written with formulized expressions. Table 3 summarizes the expressions. The formulized expressions have apparent advantages: it is easy for designers to understand each process, debug and fix errors, and record the entire process.

For example, let's take a look at the first expression from the Table 3. In the $\boldsymbol{T_{WHOLE}}$, we can see there are three parallel OR tasks. By definition of SWF-nets, it should have the multiple-choice split before the tasks ($\mathbf{T_{O-RS}}$) and the multiple-choice join after the tasks ($\mathbf{T_{O-RJ}}$). Also note that there are three nets-in-nets in the process ($\boldsymbol{T_{O-NN1}}$, $\boldsymbol{T_{O-NN2}}$, and $\boldsymbol{T_{O-NN3}}$).

Table 3: Formulized Expression for Admission Processes

Name	Formulized Expression
$\boldsymbol{T_{WHOLE}}$	$P_{O-01}\boldsymbol{T_{O-NN1}}P_{O-02}\mathbf{T_{O-RS}}$ $(P_{O-03}T_{O-03}P_{O-04}\boldsymbol{T_{O-NN2}}P_{O-05} \cap$ $P_{O-06}T_{O-05}P_{O-07}T_{O-006}P_{O-08} \cap$ $P_{O-09}T_{O-07}P_{O-10}\boldsymbol{T_{O-NN3}}P_{O-11})$ $\mathbf{T_{O-RJ}}P_{O-12}T_{O-10}P_{O-13}$
$\boldsymbol{T_{O-NN1}}$	$T_{L-01}P_{L-01}\mathbf{T_{L-OS1}}(P_{L-02}T_{L-UT1}P_{L-03} \cap P_{L-04})$ $\mathbf{T_{L-OJ1}}P_{L-LE}T_{L-UT2}P_{L-06}\mathbf{T_{L-OS2}}$ $(P_{L-07}T_{L-LC}P_{L-LB}T_{L-LTT}P_{L-09}T_{L-09}P_{L-10} \cap P_{L-11})$ $\mathbf{T_{L-OJ2}}P_{L-12}T_{L-11}$
$\boldsymbol{T_{O-NN2}}$	$T_{A-01}P_{A-01}T_{A-02}P_{A-02}\mathbf{T_{A-OS1}}$ $(P_{A-LE}T_{A-04}P_{A-04}T_{A-UT1}P_{A-05}\boldsymbol{T_{A-NN1}}P_{A-20} \cap$ $P_{A-21}\boldsymbol{T_{A-NN2}}P_{A-26})\mathbf{T_{A-OJ1}}P_{A-27}T_{A-23}$
$\boldsymbol{T_{A-NN1}}$	$\mathbf{T_{A-OS2}}\{P_{A-06}\mathbf{T_{A-OS3}}$ $(P_{A-07}T_{A-LC}P_{A-LB}T_{A-ST1}P_{A-09} \cap$ $P_{A-10}T_{A-ST2}P_{A-11})\mathbf{T_{A-OJ3}}P_{A-12} \cap$ $P_{A-13}\mathbf{T_{A-OS4}}(P_{A-14}T_{A-13}P_{A-15} \cap$ $P_{A-16}T_{A-ST3}P_{A-17}T_{A-TT}P_{A-18})$ $\mathbf{T_{A-OJ4}}P_{A-19}\}\mathbf{T_{A-OJ2}}$
$\boldsymbol{T_{A-NN2}}$	$\mathbf{T_{A-OS5}}(P_{A-22}T_{A-UT2}P_{A-23} \cap$ $P_{A-24}T_{A-20}P_{A-25})\mathbf{T_{A-OJ5}}$
$\boldsymbol{T_{O-NN3}}$	$T_{F-01}P_{F-01}\boldsymbol{T_{F-NN1}}P_{F-08}\mathbf{T_{F-RS}}$ $(P_{F-09}T_{F-09}P_{F-10}\boldsymbol{T_{F-NN2}}P_{F-13} \cap$ $P_{F-14}T_{F-13}P_{F-15}\boldsymbol{T_{F-NN3}}P_{F-18} \cap$ $P_{F-19}T_{F-17}P_{F-20}\boldsymbol{T_{F-NN4}}P_{F-36})\mathbf{T_{F-RJ}}P_{F-37}T_{F-33}$
$\boldsymbol{T_{F-NN1}}$	$T_{F-02}P_{F-02}T_{F-03}P_{F-03}\mathbf{T_{F-OS1}}(P_{F-04}T_{F-UT1}P_{F-05}$ $T_{F-06}P_{F-06} \cap P_{F-07})\mathbf{T_{F-OJ1}}$
$\boldsymbol{T_{F-NN2}}$	$T_{F-10}P_{F-11}T_{F-11}P_{F-12}T_{F-12}$
$\boldsymbol{T_{F-NN3}}$	$T_{F-14}P_{F-16}T_{F-15}P_{F-17}T_{F-16}$
$\boldsymbol{T_{F-NN4}}$	$T_{F-18}P_{F-21}\mathbf{T_{F-OS2}}\{P_{F-22}T_{F-20}P_{F-23}T_{F-21}P_{F-24}$ $T_{F-ST1}P_{F-25} \cap P_{F-26}T_{F-23}P_{F-27}T_{F-24}P_{F-28}$ $\mathbf{T_{F-OS3}}(P_{F-29}T_{F-26}P_{F-30}T_{F-27}P_{F-31}T_{F-UT2}P_{F-32}$ $T_{F-ST2}P_{F-33} \cap P_{F-34})\mathbf{T_{F-OJ3}}P_{F-35}\}\mathbf{T_{F-OJ2}}$

7. CONCLUSIONS AND FUTURE WORK

Structured modeling processes of complex collaborative commerce (c-Commerce) systems are very important for verification and management. Current Petri net and workflow analyses do not provide effective approaches to carry out such functions. Modeling workflow processes using Petri net based approaches provides powerful analysis capabilities since it can specify, for example, which tasks need to be executed and in what order.

In this paper, we discussed a previously introduced c-Commerce architecture (HCCS) that can be used in many situations. The intent was to assess this architecture and verify its effectiveness. Modeling is a practical approach to evaluate such system design. We investigated the use of Petri nets in modeling applications of this system. Petri nets abstracts and properties were reviewed and a modified workflow net which symbolizes places, transitions and arcs for modeling processes (SWF-nets) was proposed. SWF-nets' formulized expressions were derived to provide effective analysis of processes. We showed the soundness of the SWF-nets. This allows us to use standard Petri net analysis tools to verify the correctness of the SWF-nets.

As a case study, graduate program admission processes in a university were studied and mapped into the SWF-nets. We showed that the complicated admission processes can be presented in a much simpler form by using SWF-nets. The method illustrated the usefulness and functionality of the HCCS architecture as well. Developing complete processes from college admission to graduation and simulating the whole process using existing WF-net software packages, such as YAWL (www.yawl-system.com), will be considered in future work. Practical issues and any limitations can then be investigated further.

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