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A STOCHASTIC WORKFLOW-SUPPORTED ORGANIZATIONAL SOCIAL NETWORK MODEL

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Abstract. *This paper proposes a stochastic model that formalizes a workflow-supported organizational social network with holding probabilities on every arc, and it is named as stochastic workflow-supported organizaitonal social network model. The proposed stochastic model can be algorithmically discovered from the probabilistic binding relationships between activities and performers in the information control net of a corresponding workflow procedure, and it is used to semantically convey a quantitative analysis of the collaborative comradeships formed through performing workflow-supported activities in an organization. Through the stochastic workflow-supported organizational social network model, it is eventually possible to analyze the degrees of collaborations as well as the progression of the collaborative comradeship dynamics. In conclusion, this paper mathematically formulates the stochastic model and describes its implications as an impeccable solution to be used in not only discovering human-centered organizational behavioral dynamics but also measuring the human-centered fidelities of workflow procedures via model-log comparisons as workflow-supported organizational knowledge.*
Keywords: Stochastic workflow model, Probabilistic activity-to-performer bindings, Workflow-supported organizational social network

1. **Introduction.** Organizations have multiple models – some may be explicit and formal; others are implicit and informal [4]. Some models focus on data processing, some on process modeling, some on people and social networks, etc. A typical open-ended meta-model for understanding, describing, and analyzing workflow procedures is the information control net (which is abbreviated as ICN.) [5,9]. Many workflow-supported organizational information systems [7] have modeled process-aware business operational activities by using ICNs. The steady evolution of the ICN meta-model over the years has made available many augmentations (*e.g.*, colored ICNs and stochastic ICNs [15]) and many perspectives (*e.g.*, actor-oriented perspective [10]). The ICN consists of perspectives [9] that include the process, the informational, and the resource (invoked-applications, roles, and performers) perspectives.

Member models of the ICN family have been used for modeling office activities [11] in numerous organizational domains. In this paper[1], we focus on the comradeship dynamics between workflow-supported co-workers in a workflow-supported organization, in particular. An organization is used to have multiple historical information repositories [7,12]. For example, some may be transaction logs [2], communication records, runtime performer binding audit trails [2], etc. We are especially interested in the logs (audit trail) of runtime performer bindings in enacting organizational workflow procedures. By analyzing the relative frequency of each performer's runtime bindings in such a log, we

[1]This paper is extended from the conference paper [8] published in the Proceedings of the BMFSA2015, Kumamoto, Japan. It is also a subsequent result to the paper [1] published in ICIC Express Letters.

are able to discover the evolution of a collaborative comradeship (work-sharing and work-transferring) network [17] among workflow-supported co-workers in some time points at intervals of a certain time-period. Such a collaborative comradeship network is formally represented by a workflow-supported organizational social network model [16], and its evolutionary process (network dynamics [14]) can be statistically formulated by a stochastic workflow-supported organizational social network model, which was firstly introduced in the conference paper [8] that is to be extended in this paper.

Due to the page limitation, the paper is simply organized by four sections including introduction and conclusion. In the next two consecutive sections that are the main contribution, the paper starts from describing the formal representation of the information control net with assigning probabilities to activity-to-performer bindings [1], formalizes the basic concept of the proposed stochastic model, and summarizes its implications.

2. **Extension of the Information Control Net.** In this section, we try to extend the original information control nets [5,9,15] so as to specify the stochastic activity-to-performer bindings [1,3] by a theory of probability [12,13]. In general, an information control net is a directed graph where every node (or vertex) has a unique ID number, a (not necessarily unique) label, and a type; every arc (or edge) is defined as an ordered pair $<n_1, n_2>$ of nodes. Directed arcs connect nodes, and semantically denote precedences on the flow of control. Note that there are 7 node types [15] defined: activity, OR-fork, OR-join, AND-fork, AND-join, LOOP-fork, and LOOP-join. Due to the page limitation, we will not give a detailed account of the formal definitions of these nodes in this paper. We also assume that all extended ICNs must be match-paired, proper-nested, and non-empty. Informally, the match-paired and proper-nested property [9] means that all control constructs must be entirely contained within other control constructs, and may not interleave nor have unstructured "GO TO" arcs. This is defined formally in the following sentences using the concepts of block initiation nodes and block termination nodes. The control node types of OR-split, AND-split, and LOOP-join are categorized as block initiation nodes. The control node types of OR-join, AND-join, and LOOP-split are categorized as block termination nodes. An extended ICN is properly nested iff there is a pairing of control nodes such that each OR-split is paired with an OR-join, each AND-split is paired with an AND-join, and each LOOP-split is paired with a LOOP-join. Conclusively, an extended ICN with stochastic performer bindings [1,6] must be temporally combined with manual activities and automative activities, and their control-gateways paired with its block initiation/termination nodes, n_i/n_t, in such a way that:

- $n_i \ll n_t$
- $d^{out}(n_i) + d^{in}(n_i) = d^{out}(n_t) + d^{in}(n_t)$
- $(n_i \ll n_i^*) \Longrightarrow (n_t^* \ll n_t)$ where (n_i, n_t) and (n_i^*, n_t^*) are matched pairings
- Every execution sequence (path) that reaches n_i must eventually reach n_t

(Note that the notation $a \ll b$ means that node a precedes node b in all simple paths to b from the initial node of the graph.) A block initiation node is non-empty if there is at least one activity node on each path to its matching block termination node. An ICN is non-empty if it contains at least one activity (manual or automatic) node, and all block initiation nodes are non-empty.

The extension on the information control nets is on defining the probabilistic activity-to-performer bindings [1], as shown in the right-hand side of Figure 1. That is, this paper tries to extend the information control net to formally specify a probability on every pair of activity and performer by adopting a theory of probability, and it names them "probabilistic activity-to-performer bindings [1]". The primitive properties of the probabilistic activity-to-performer bindings are formally defined as follows.

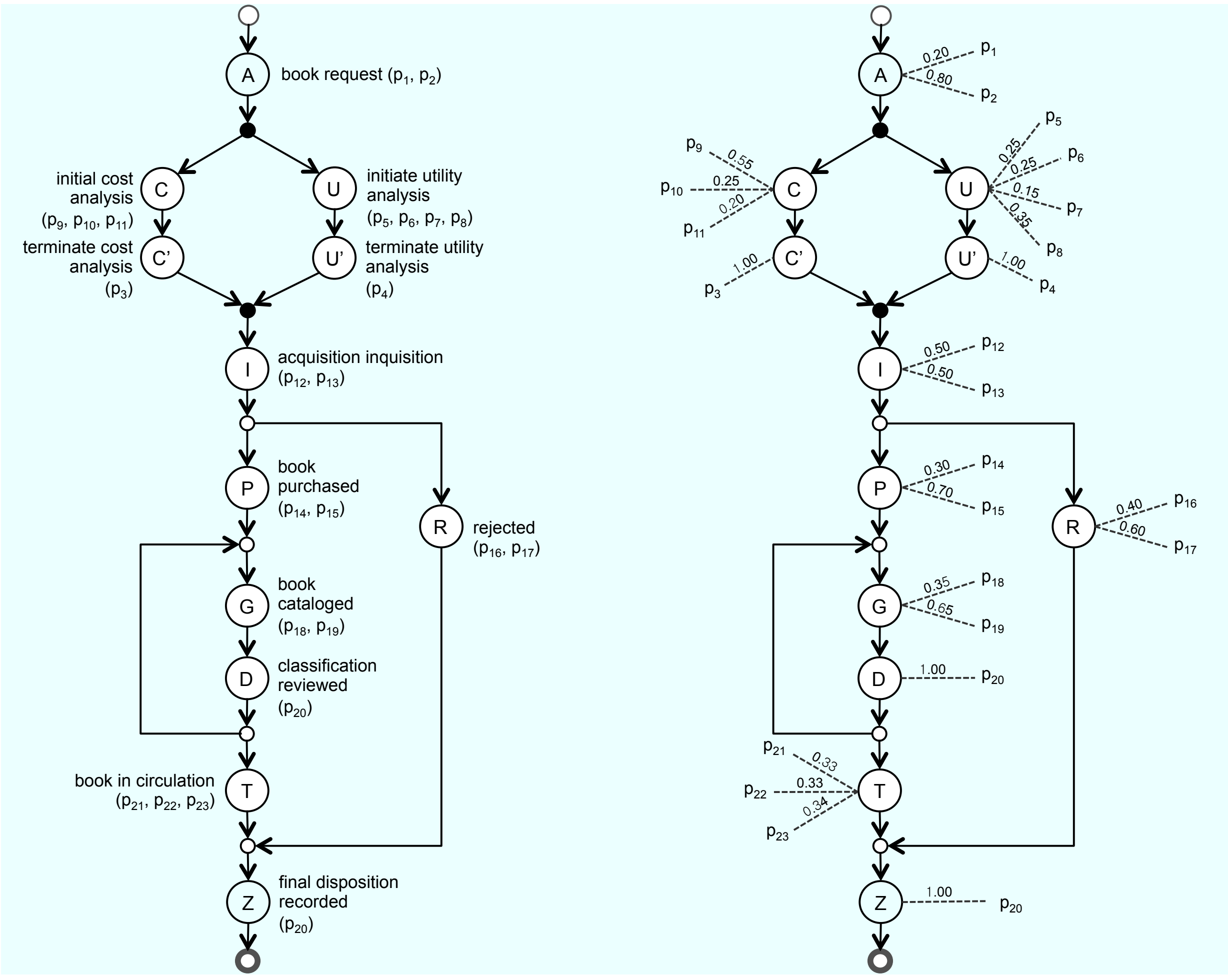

FIGURE 1. The library book acquisition workflow [18]: an information control net and its probabilistic activity-to-performer bindings

- A set of probabilistic activity-to-performer bindings in an information control net is represented by an undirected affiliation graph where an activity node has a unique ID number and a (not necessarily unique) label; every arc (or edge) between the activity and its affiliated performers is defined as a pair $<n_a, p_m>$ of bipartite nodes, and has a probability (in the $(0, 1]$ range) associated with it denoted $pr<n_a, p_m>$. Undirected arcs connect activity-nodes to performer-nodes, and semantically denote affiliative relationships. The probabilistic activity-to-performer bindings are only applied to the activity type out of the 7 node types defined in ICN.
- **P** is a set of workflow-performers, and **A** is a set of activities. $|\mathbf{A}|$ and $|\mathbf{P}|$ are the numbers of activities and performers, respectively, that are involved in a specific workflow procedure.
- There are two types of activity, manual (human-intervention) activity and automatic (human-nonintervention) activity:
  - $(\exists\{<n_a^m, p_1> \dots <n_a^m, p_k>\} \wedge k \geq 1)$: Semantically each manual activity node, n_a^m, has affiliated with at least one performer or more.
  - (*No Arc between* n_a^a *and performers*): Semantically, each automatic activity node, n_a^a, has unaffiliated with any performer.
- Every manual activity, n_a^m, has $d^{group}(n_a^m) = k$ and its affiliated performers have $d^{multi}(p_i) = 1$, $1 \leq i \leq k$. At the same time, every arc in a manual activity has a probability, $pr<n_a^m, p_k> = P_i$, where $1 \leq i \leq k$, $\sum_{i=1}^{k} P_i = 1.0$, and $k \leq |\mathbf{P}|$.

- Probabilistically each affiliation arc is associated with a probability, which is one of $P_1 \ldots P_m$: $(pr{<}n_a^m, p_1{>} = P_1 \wedge pr{<}n_a^m, p_2{>} = P_2 \wedge \ldots \wedge pr{<}n_a^m, p_k{>} = P_k \wedge P_1 > 0.0 \wedge P_2 > 0.0 \wedge \ldots \wedge P_k > 0.0 \wedge P_1 + P_2 + \cdots + P_k = 1.0 \wedge 1 \leq k)$.
- In probabilistic activity-to-performer bindings, the activity compartment consists of manual activity nodes and automatic activity nodes. Each manual activity node, n_a^m, has group-degree, d^{group}, of k, and each automatic activity node, n_a^a, has group-degree, d^{group}, of $0(zero)$: $(d^{group}(n_a^m) = k \wedge 1 \leq k \leq |\mathbf{P}| \wedge n_a^m \in \mathbf{A})$.
- In probabilistic activity-to-performer bindings, the performer compartment consists of a set of workflow-performers affiliated into a corresponding workflow procedure. Each performer node has multi-degree, d^{multi}, of l: $(d^{multi}(p_i) = l \wedge 1 \leq l \leq |\mathbf{A}| \wedge p_i \in \mathbf{P})$.

3. **Stochastic Workflow-Supported Organizational Social Network Model.** In this section, we start from introducing the basic concept and definition of workflow-supported organizational social network model [16] that can be discovered from an information control net of workflow procedure. Basically, the origin of the workflow-supported social network model is the actor-oriented workflow model [10], and its rationale is on where it represents the collaborative behaviors of acquiring activities among actors in a workflow procedure. Those workflow-supported organizational behaviors form a special type of organizational social networks reflecting collaborative comradeships among the workflow-performers. Each of the collaborative comradeships is graphically represented by a set of incoming and outgoing directed arcs labeled with activities. In consequence, it is possible to shape a performer-based network by analyzing the flow of controls among activities and a set of activity-to-performer bindings in an information control net, and the performer-based network becomes a theoretical basis of the workflow-supported organizational social network model.

In the previous section, we have formally described the probabilistic activity-to-performer bindings as an extension of the information control net. It is possible to define a stochastic performer-based model from an extended information control net, and it is named as a stochastic workflow-supported organizational social network model that is the main contribution of this paper. The following are the details of the formal representation of the proposed stochastic model:

- A stochastic workflow-supported organizational social network model is represented by a directed multigraph where each workflow-performer node has a unique ID number and a (not necessarily unique) name; each arrow (directed arc or edge) including multiple[2] and loop[3] edges between the performers is defined as an ordered pair, ${<}p_a, p_b{>}$, and the ordered pair has a label with a probability (in the $(0, 1]$ range) and a single acquiring activity, α, of the head, p_b, of the arrow, which is denoted by $[pr{<}p_a, p_b{>}, \alpha]$, where $pr{<}p_a, p_b{>} = pr{<}\alpha, p_b{>}$.
- Directed arcs connect performer-nodes to performer-nodes, and semantically denote collaborative comradeships. The probabilistic activity-to-performer bindings are only applied to the manual activity type out of the 7 node types defined in the information control net; therefore, the vertices in a stochastic performer-based model are representing the performers assigned to only the manual activities in a corresponding information control net.
- $\mathbf{P}$ is a set of workflow-performers, and $\mathbf{A}$ is a set of manual activities. $|\mathbf{A}|$ and $|\mathbf{P}|$ are the numbers of manual activities and performers, respectively, that are involved in a specific workflow procedure.

[2]Multiple edges are two or more edges that connect the same two vertices.
[3]A loop edge is a directed edge that connects a vertex to itself.

- Multiple directed arcs that are two or more edges that connect the same two vertices, p_a and p_b, have different labels of $\{[pr^1{<}p_a, p_b{>}, \alpha_1], [pr^2{<}p_a, p_b{>}, \alpha_2], \ldots, [pr^m{<}p_a, p_b{>}, \alpha_m], 2 \leq i \leq m, \alpha_1 \neq \alpha_2 \neq \cdots \neq \alpha_m$, and $m \leq |\mathbf{A}|\}$, respectively.
- Every node, $p_a \in \mathbf{P}$, has in-degree, d^{in}, of k, and out-degree, d^{out} of s: $d^{in}(p_a) = k \wedge 1 \leq k \leq |\mathbf{P}| \wedge d^{out}(p_a) = s \wedge 1 \leq s \leq |\mathbf{P}|$.

The directed multigraph of the stochastic model implies a collaborative comradeship network with probabilistic work-transferring behaviors through the probabilistic precedence (candidate-predecessor and candidate-successor) comradeships among the performers in a workflow procedure. In terms of defining the predecessors and successors of performers, we would use the prepositional word, "*candidate*", because the role-to-performer bindings in an information control net are one-to-many relationships, and so the performer selection mechanism will choose one out of the assigned performers mapped to a corresponding role during the underlying workflow procedure's runtime. Additionally, the activities on the incoming directed arcs of a performer are representing the activities acquired by the performer itself, and the activities on the outgoing directed arcs are the activities transferred to the other performers in the pairs.

At this moment, it is important to emphasize that the stochastic workflow-supported organizational social network model will not be modeled or designed but automatically discovered from an extended information control net of workflow procedure. So, we need to devise an automatic discovery methodology for composing a stochastic workflow-supported organizational social network model, and it can be algorithmically discovered by exploring the internal human-centered properties of an extended information control net, such as δ_i, δ_o (the flow of control) [9], ε_p (activity-to-role binding) [9], and π_c (role-to-performer bindings) [9]. In consequence, the activity-to-performer bindings are obtained by applying the function, $\pi_c(\varepsilon_p(\alpha))$, $\alpha \in \mathbf{A}$, to a corresponding information control net. However, we would leave the algorithmic discovery methodology as future work.

Due to the page limitation, we will not provide the details of how to discover it from the extended information control net with probabilistic activity-to-performer bindings. We can simply give a graphical representation of the stochastic performer-based

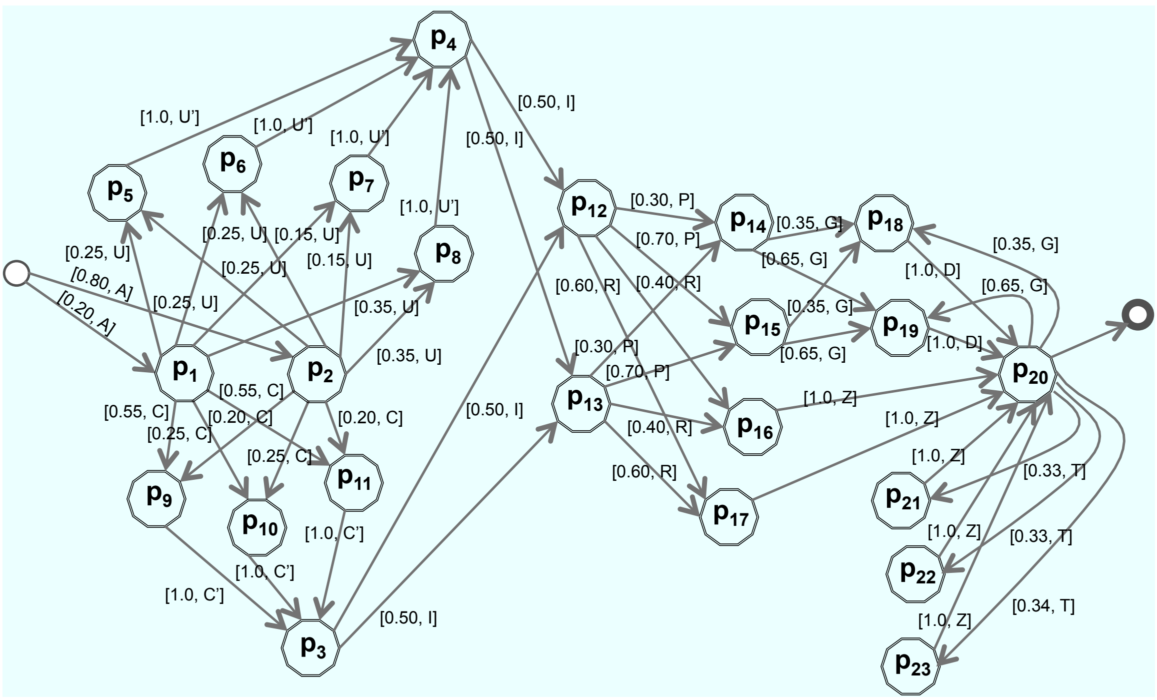

FIGURE 2. A stochastic workflow-supported organizational social network from the extended library book acquisition workflow

model through Figure 2 that is illustrating a stochastic workflow-supported organizational social network spawned from the extended information control net with stochastic activity-to-performer bindings of the library book acquisition workflow [15,18]. As you see in Figure 1, the extended information control net has the many-to-many cardinality in the mappings of activities and performers, and so there may be multiple arcs connecting the same two performers with labeling their acquiring activities and probabilities. The probability labels on every arc in Figure 2 come out of the notation, $[pr{<}p_a, p_b{>}, \alpha]$. For instance, $[pr{<}p_1, p_5{>}, \mathtt{U}] = [0.25, \mathtt{U}]$, $[pr{<}p_1, p_6{>}, \mathtt{U}] = [0.25, \mathtt{U}]$, $[pr{<}p_1, p_7{>}, \mathtt{U}] = [0.15, \mathtt{U}]$, $[pr{<}p_1, p_8{>}, \mathtt{U}] = [0.35, \mathtt{U}]$; $\left(\sum_{i=1}^{4}[P_i, \mathtt{U}]\right) = 1.0$, $\delta_i(\mathtt{U}) = \mathtt{A}$, $p_1 \in \mathbf{P}_p = \pi_c(\varepsilon_p(\mathtt{A}))$, $p_5, p_6, p_7, p_8 \in \mathbf{P}_s = \pi_c(\varepsilon_p(\mathtt{U}))$.

In this paper, we introduce a new and novel concept of the stochastic workflow-supported organizational social network model for representing the workflow-supported collaborative comradeship network via a new probabilistic extension of information control nets. This allows us to do both qualitative and quantitative information systems analyses. The main thrust of this paper is concerned with presentation and characterization of organizational social networks with performers' stochastic binding formalism, and its implications in terms of discovering human-centered knowledge in workflow-supported organizations.

4. **Conclusion.** This paper is aimed to deliver a solid mathematical presentation of a new and novel concept, which is the stochastic workflow-supported organizational social network model. That is, we extended the classic information control net so as to support the theory of probability in binding activities into performers, and proposed the stochastic performer-based model that reflects the performers' collaborative behaviors in a workflow-supported organization. This proposed stochastic model gives us an effective means not only to represent a valuable workflow-supported collaborative comradeship network, but also to analyze the progression of the collaborative comradeship network dynamics. Additionally, it is important to emphasize that we did not differentiate the single-performer binding activity type from the group-performer binding activity (realtime groupware activity) type that implies that a group of performers are simultaneously assigned to cooperatively perform a single manual activity; almost all current available workflow models do not support such a realtime groupware activity type. Therefore, as future work, we need to cope with the concept of group-performer bindings in formalizing the proposed concept.

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