Multi-Criteria Task Assignment in Workflow Management Systems

Minxin Shen[1] Gwo-Hshiung Tzeng[2] Duen-Ren Liu[3]
[1, 3] *Institute of Information Management, National Chiao Tung University, Taiwan*
{shen, dliu}@iim.nctu.edu.tw
[2] *Institute of Management of Technology, National Chiao Tung University, Taiwan*
ghtzeng@cc.nctu.edu.tw

Abstract

During workflow design, workflow modelers generally specify the performers of a task by their organizational role. However, during workflow enactment, numerous workers with different skills and expertise may share the same role in an organization, making it hard to select appropriate individuals based merely on the assignment relation between a role and a task. To bridge the gap between abstract roles and real workers, this work proposes a multi-criteria assessment model capable of evaluating the suitability of individual workers for a specified task according to their capabilities, social relationships, and existing tasks. Candidates are ranked based on their suitability scores to support workflow administrators in selecting appropriate workers to perform the tasks assigned to a given role. The proposed assessment model overcomes the lack of role-based task assignment in current workflow management systems.

1. Introduction

As an effective process management tool, workflow management systems (WfMSs) allow a business to analyze, simulate, design, enact, control and monitor the processes involved in its general business [6, 10]. A WfMS-controlled business process is formally described using a workflow definition that specifies the order in which tasks are performed and those who perform them. A workflow modeler generally specifies the performer of a task using an organizational role rather than a specific worker in a workflow definition (e.g., [3, 7, 8, 16, 24]). The use of abstract roles means that a workflow modeler does not need to alter workflow definitions after adjusting the positions or duties of workers. *Role-based task assignment* thus reduces variation in workflow definitions.

However, various workers with different skills may share the same role in an organization, and selecting suitable individuals from them to perform a specified task is essential for the effective utilization of human resources. For example, assume the task “hardware repair” is assigned to the role “computer engineer” in a workflow definition. Numerous employees who are computer engineers may have different areas of expertise, such as Java programming, homepage design, and hardware repair, and selecting an engineer specialized in hardware for facility repair is difficult using role-based assignment. This work aims to develop a method for supporting a workflow administrator or WfMS in choosing appropriate actual workers to perform the tasks assigned to a given role in a workflow definition.

Workflow management-related research has overcome the limitation of role-based assignment either by human intervention or the design of specific rules to determine the mapping between roles and workers (e.g., [3, 7]). These approaches only consider the capability of workers to perform assigned tasks. Appropriate assignment of tasks to workers based on evaluation of their suitability and resource constraints is well-known in the field of operations research as the *personnel placement problem* (also called the assignment problem) [4]. The conventional assignment problem employs crisp values to assess the suitability of workers for a given task, and distributes tasks according to capability matching. Liang and Wang [11] applied fuzzy set theory to revise the conventional assignment problem to overcome the vagueness of human decision-making. Subsequently, Yaakob and Kawata [20] enhanced Liang-Wang’s model by making it also consider the social relationships among workers in a teamwork environment. However, workers may have existing tasks to cope with before the assignment of a new set of tasks, and [11] and [20] ignore the influence of previously assigned tasks.

To overcome the limitations of role-based assignment in WfMSs, a multi-criteria assessment model is proposed

0-7695-1874-5/03 $17.00 (C) 2003 IEEE

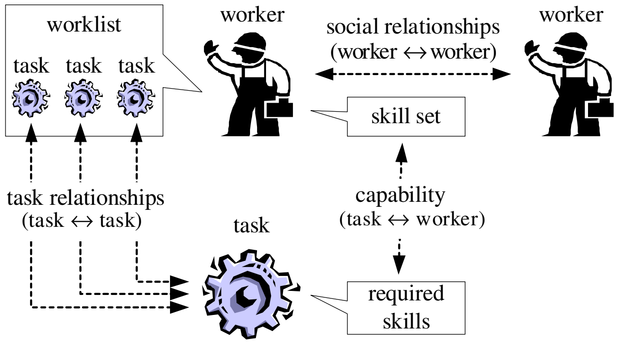

Fig. 1. Evaluation criteria

that assesses the suitability of candidate workers based on capabilities, social relationships, and task relationships in a fuzzy environment. Candidate workers are ranked according to suitability scores, allowing the most suitable workers to be appointed/recommended to perform the tasks assigned to a given role. The analysis of capability and social relationships in the assessment model is similar to that in [11] and [20]. Furthermore, the relationships between the tasks a workflow administrator wishes to assign and those tasks already assigned to workers are analyzed both qualitatively and quantitatively. The quantitative impact is workload balancing, while the qualitative impacts include separation of duty, specialization of labor, and job enrichment. An illustrative example is presented to demonstrate how the model can be applied to practical situations. The result shows that previously assigned tasks significantly influence worker suitability, and thus the proposed model enhances conventional assessment models and overcomes the lack of role-based task assignment.

The rest of this paper is organized as follows: Section 2 reviews the literature on task assignment, and Section 3 introduces the basic concept of fuzzy numbers. Section 4 then presents the novel assessment model for ranking candidate workers for a given task. Next, Section 5 demonstrates a numerical example. Finally, conclusions are made in Section 6.

2. Review of the task assignment problem

Workflow design frequently assigns tasks to abstract roles rather than to specific workers. [16] and [24] presented detailed organizational meta-models to support organizational modeling and role-based task assignment for workflow applications. Moreover, [3] and [7] proposed formal languages to describe user-role and role-task assignments. However, as mentioned previously, a WfMS must select actual workers (*role instances*) to complete a task during workflow run-time. Discovering role instances is also termed the *role resolution problem*. Therefore, [3, 7] also defined query languages capable of identifying qualified workers fulfilling a certain role, but they mainly considered capability matching. Moreover, when the supply of candidate workers exceeds the demand, no ranking mechanism is proposed for recommendations based on degree of fitness.

In the operations research field, the manpower placement problem involves suitable matching of workers with tasks. Conventional approaches use exact values to assess worker suitability. Liang and Wang [11] employed fuzzy set theory to tackle the vagueness of human assessment in manpower placement. This approach only evaluates personnel suitability based on worker capabilities. Yaakob and Kawata [20] further considered the social relationships among workers to establish a more effective task force.

As Fig. 1 shows, these investigations fail to consider the influence of tasks previously assigned to workers (in his/her worklist). In practice, a knowledge worker may participate in multiple projects or simultaneously work on many jobs. Appropriate and fair task assignment requires considering the impacts of the relationships between the new task and tasks that are already assigned to workers. The impact of task relationships includes workload balancing and job design policies such as separation of duty, specialization, and job enrichment.

3. Preliminaries

Fuzzy set theory, as proposed by Zadeh [22], deals with the vague, imprecise, and uncertain problems involved in human decision-making environments [1]. A fuzzy set $\tilde{Z}$ is associated with a membership function $\mu_{\tilde{z}}(x)$ which indicates the degree (or grade) that x belongs to $\tilde{Z}$. This section introduces basic concepts about fuzzy numbers and linguistic variables that this work uses to evaluate criteria weightings and worker suitability.

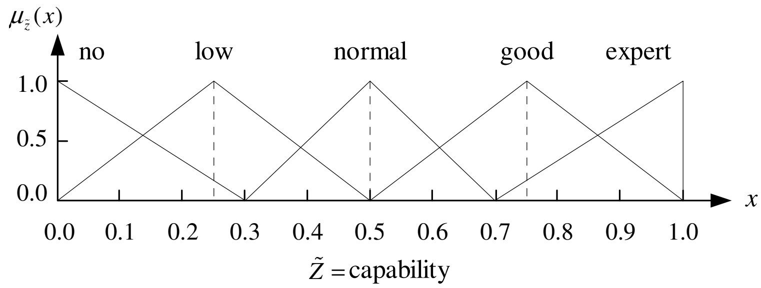

Fig. 2. Linguistic values of "capability"

3.1. Fuzzy numbers and linguistic variables

A fuzzy number is a fuzzy set defined on real line $\Re$. Fuzzy numbers can be used to represent imprecise numerical quantities, e.g., "close to 6" and "about 7", or linguistic terms, e.g., "good" and "bad". Triangular fuzzy numbers are widely used owing to their simplicity and solid theoretical basis [15]. The membership function of a triangular fuzzy number $\tilde{Z} = (l, m, r)$, $\mu_{\tilde{z}}(x): \Re \rightarrow [0,1]$, is defined as follows:

$$\mu_{\tilde{z}}(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m, \\ (r-x)/(r-m), & m \le x \le r, \\ 0, & \text{otherwise,} \end{cases}$$

where $-\infty < l \le m \le r < \infty$.

Let $\tilde{A}_1 = (l_1, m_1, r_1)$, $\tilde{A}_2 = (l_2, m_2, r_2)$, and let k be a positive real number, then the arithmetic operations of triangular fuzzy numbers are as follows: addition $\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, r_1 + r_2)$, subtraction $\tilde{A}_1 \ominus \tilde{A}_2 = (l_1 - r_2, m_1 - m_2, r_1 - l_2)$, multiplication $\tilde{A}_1 \otimes \tilde{A}_2 \cong (l_1 l_2, m_1 m_2, r_1 r_2)$, $l_1, l_2 \ge 0$, $k \otimes \tilde{A}_1 \cong (kl_1, km_1, kr_1)$, and division $\tilde{A}_1 \oslash \tilde{A}_2 \cong (l_1 / r_2, m_1 / m_2, r_2 / l_1)$, $l_1 \ge 0$, $l_2 > 0$. Notably, the multiplication and division of $\tilde{A}_1$ and $\tilde{A}_2$ are approximate triangular fuzzy numbers [9].

For decision-makers, some data can be described qualitatively by linguistic terms but is difficult to quantify numerically. Zadeh [21] proposed the notion of *linguistic variables* to tackle such problems. A linguistic variable is a variable whose values are words or sentences in a natural language. For example, the values of the linguistic variable "capability" can be described using five linguistic scales: no, low, normal, good, and expert. Triangular fuzzy numbers can represent these linguistic scales, as shown in Fig. 2. Linguistic variables and fuzzy numbers allow decision-makers to use linguistic scales to assess worker capabilities.

3.2. Ranking fuzzy numbers

The proposed evaluation model represents final suitability scores using fuzzy numbers. Before ranking, fuzzy numbers are defuzzified to obtain their Best Non-fuzzy Performance values (BNP) [18, 19]. Although various defuzzification approaches have been proposed [2, 23], this work adopts the center of area (COA) approach to rank fuzzy numbers because this method is simple, practical, and does not involve evaluator preference. The COA method generates the center of gravity of the possibility distribution of a fuzzy number. Meanwhile, the BNP value of a triangular fuzzy number $\tilde{Z} = (l, m, r)$ can be obtained by Eq. (1).

$$BNP = l + \left[(r-l) + (m-l) \right] / 3 \quad (1)$$

Therefore, candidate workers are ranked according to the BNP values of their suitability score.

4. Task assignment model

This section first describes how to assess worker suitability using three criteria (i.e., capabilities, social relationships, and task relationships) and then presents the evaluation procedure.

4.1. Problem formalization

Given a task J_{new} in a workflow definition, task J_{new} is assigned to an abstract role played by a set of workers U_i. Each candidate worker U_i is associated with a worklist which records the tasks assigned before J_{new}. Task J_{new} requires k skills (C_t, t = 1, 2, …, k) and the respective weight of C_t is $\tilde{w}(J_{\text{new}}, C_t)$. These candidate workers are ranked according to their suitability for performing J_{new}.

As shown in Fig. 1, task assignment should consider three relationships. First, the relationships between the skill set of a worker and the skills required for a task determine whether the worker is capable of performing the task, as discussed in Section 4.2. Second, social relationships among workers are important, as discussed in Section 4.3. Finally, Section 4.4 discusses the relationships among tasks.

4.2. Capabilities

Let $\tilde{e}\left(U_i, C_t\right)$ be the assessment score of worker U_i on skill C_t, and let $\tilde{w}\left(J_{\text{new}}, C_t\right)$ be the weighting of C_t. The weighting $\tilde{w}\left(J_{\text{new}}, C_t\right)$ is a linguistic variable with five possible values: not important, barely important, moderately important, very important, and extremely important, where the corresponding fuzzy numbers are (0, 0, 0.1), (0, 0.3, 0.5), (0.3, 0.5, 0.7), (0.5, 0.7, 0.9), (0.7, 0.9, 1), respectively. The capability assessment scores are represented by five linguistic scales: no, low, normal, good, and expert, where the corresponding fuzzy numbers are (0, 0, 0), (0, 0.2, 0.4), (0.2, 0.4, 0.6), (0.4, 0.6, 0.8), (0.6, 0.8, 1), respectively.

For J_{new}, the total suitability of capability of U_i can be evaluated by Eq. (2).

$$\tilde{E}_{\text{CAP}}(U_i) = \frac{1}{k} \otimes \sum_{t=1}^{k} \left[\tilde{e}\left(U_i, C_t\right) \otimes \tilde{w}(J_{\text{new}}, C_t) \right] \tag{2}$$

4.3. Social relationships

Let $\tilde{E}_{\text{IND}}(U_i)$ denote the suitability of a worker for performing J_{new}. If J_{new} must be performed by a team of m workers, then the suitability of a candidate team can be obtained by Eq. (3).

$$\tilde{E}_{\text{CAND}} = \sum_{i}^{m} \tilde{E}_{\text{IND}}(U_i) \tag{3}$$

However, the teamwork environment should further consider social relationships among team members. This work adopts Yaakob and Kawata's prescription [20], i.e., pair comparison, to assess the impact of social relationships. In a team, the relationships between every pair of workers are evaluated and then totaled. Eq. (4) obtains the total score of social relationships for a team.

$$\tilde{E}_{\text{RL}} = \frac{1}{\mathrm{C}_2^f} \otimes \sum_{p,q} \tilde{e}_{\text{RL}}\left(U_p, U_q\right), \tag{4}$$

where $\mathrm{C}_2^f = f\left(f-1\right)/2$, and f denotes the number of team members. $\tilde{e}_{\text{RL}}\left(U_p, U_q\right)$ is the evaluation score of the social relationship between workers U_p and U_q, and $\tilde{E}_{\text{RL}}$ represents the total evaluation score of social relationships among team members. The score of $\tilde{e}_{\text{RL}}\left(U_p, U_q\right)$ is assessed using five linguistic scales: worst, poor, fair, good, and best, where the corresponding fuzzy numbers are (0, 0, 0), (0, 0.3, 0.5), (0.3, 0.5, 0.7), (0.5, 0.7, 0.9), (0.7, 0.9, 1), respectively. After adding the impact of social relationships, the suitability score of a candidate team is assessed using Eq. (5).

$$\tilde{E}_{\text{TEAM}} = \tilde{E}_{\text{CAND}} \oplus \tilde{E}_{\text{RL}} \tag{5}$$

4.4. Task relationships

Previously assigned tasks are considered both quantitatively and qualitatively. First, the quantitative effect concerns *workload balancing*. Only considering worker capabilities during task assignment may result in the ratchet effect [13], i.e., abler workers being assigned a heavier workload. Therefore, workload should also be considered to ensure tasks are assigned fairly. This work employs the total of work hours remaining for all previously assigned tasks to measure worker workload. Work hours are represented by fuzzy numbers, e.g., $\tilde{3}$ indicates approximately three hours. If worker U_i needs $\tilde{T}_{ij}$ hours to finish the jth task on his/her worklist, then his/her workload is $\sum_j \tilde{T}_{ij}$. Since workers with a heavier workload should obtain a lower suitability score, Eq. (6) uses total worker workload ($\sum_{i,j} \tilde{T}_{ij}$) minus the workload of U_i ($\sum_j \tilde{T}_{ij}$) to revise the suitability score. Moreover, the score is normalized.

$$\tilde{E}_{\text{LOAD}}(U_i) = \left(\sum_{i,j} \tilde{T}_{ij} - \sum_j \tilde{T}_{ij}\right) \oslash \left(\sum_i \left(\sum_{i,j} \tilde{T}_{ij} - \sum_j \tilde{T}_{ij}\right)\right) \tag{6}$$

Second, this work further considers the qualitative properties of previously assigned tasks when assigning J_{new} since the relationships among these tasks may be *conflicting* or *complementary*. Conflicting tasks must be performed by different workers to prevent fraud; accounting and auditing are examples of conflicting tasks. The requirement represents the *Separation of Duty* security principle [5, 14, 17]. Additionally, tasks complement each other if having similar capability requirements. Therefore, complementary tasks should be performed by the same worker to increase productivity. Detail analyses are discussed below.

A worker cannot perform J_{new} if it conflicts with some tasks on his/her worklist, and the worker can thus be eliminated from a set of candidate workers. Specifying the rules of separation of duty is beyond the scope of this work, and the constraints of separation of duty are assumed to be fulfilled by a security application such as Adage [17]. Consequently, workers associated with conflicting tasks are excluded from the list of candidate workers.

Similar tasks are assigned to the same worker based on the following principles: specialization of labor, accumulation of experience, and the learning curve effect [13]. A worker thus obtains a higher suitability score if the tasks on his/her worklist are more similar to J_{new}. According to the similarity measure [12], i.e., the degree of equality of two fuzzy sets, Eq. (7) assesses the similarity between J_{new} and the jth task in the worklist of worker U_i with regard to skill C_t. Eq. (8) thus obtains the similarity between J_{ij} and J_{new}, and Eq. (9)

determines the total similarity between J_{new} and all tasks already assigned to worker U_i (where n denotes the number of tasks in the worklist of U_i). Notably, the results of Eqs. (7) and (8) are crisp values, and Eq. (9) transforms its resultant crisp value a into a fuzzy number $\tilde{a} = (a, a, a)$.

$$s\left(J_{ij}, J_{\text{new}}, C_t\right) = \frac{\text{Area of}\left[\tilde{w}\left(J_{ij}, C_t\right) \cap \tilde{w}\left(J_{\text{new}}, C_t\right)\right]}{\text{Area of}\left[\tilde{w}\left(J_{ij}, C_t\right) \cup \tilde{w}\left(J_{\text{new}}, C_t\right)\right]} \quad (7)$$

$$S\left(J_{ij}, J_{\text{new}}\right) = \frac{1}{k}\sum_{t=1}^{k} s\left(J_{ij}, J_{\text{new}}, C_t\right) \quad (8)$$

$$\tilde{E}_{\text{SIM}}(U_i) = \frac{1}{n}\sum_{j=1}^{n} S\left(J_{ij}, J_{\text{new}}\right) \quad (9)$$

Although the proposed model assigns tasks according to the specialization of labor, some companies apply job enrichment in their job design policy [13], i.e., assigning a variety of jobs to a worker to vary his/her work life and capabilities. The similarity score can be reversed to accommodate such a policy, i.e., the suitability scores of workers will increase with the degree of difference between the tasks they are already associated with and the new task.

4.5. Evaluation procedure

The evaluation procedure that considers the above three criteria (skill, worker, and task relationships) is described as follows:

Step 1. List candidate workers, and eliminate workers already performing conflicting tasks.

Step 2. Evaluate the capability $\tilde{E}_{\text{CAP}}(U_i)$ for each candidate worker U_i .

Step 3. Evaluate the task similarity $\tilde{E}_{\text{SIM}}(U_i)$ and workload $\tilde{E}_{\text{LOAD}}(U_i)$ for each candidate worker U_i .

Step 4. The suitability score of each candidate worker U_i is $\tilde{E}_{\text{IND}}(U_i) = \tilde{E}_{\text{CAP}}(U_i) \oplus \tilde{E}_{\text{SIM}}(U_i) \oplus \tilde{E}_{\text{LOAD}}(U_i)$.

Step 5. Group workers into candidate teams. The suitability of a candidate team is $\tilde{E}_{\text{CAND}} = \sum_i^m \tilde{E}_{\text{IND}}(U_i)$, where m denotes the number of workers required.

Step 6. Evaluate social relationships $\tilde{E}_{\text{RL}}$ for each candidate team.

Step 7. The suitability score of a candidate team is $\tilde{E}_{\text{TEAM}} = \tilde{E}_{\text{CAND}} \oplus \tilde{E}_{\text{RL}}$.

Step 8. Rank candidate teams according to their $\tilde{E}_{\text{TEAM}}$.

5. An illustrative example and discussion

This section uses a simulated example to illustrate the application of the proposed assessment model, and then discusses the results of this example.

5.1. Example description

A workflow definition assigns the task "system modification" to the role "computer engineer". Workers U_1, U_2, …, U_5 are computer engineers, and a workflow administrator wishes to select two of them to perform the task "system modification". Table 1 lists the required skills and relative importance weighting for the tasks that are assigned to computer engineers. Table 2 lists the ratings of worker capabilities obtained from human resource (HR) databases. Meanwhile, Table 3 lists the ratings of social relationships among workers (for simplicity, assume their relations are symmetric).
Current job allocation and workload are as follows. Notably, workload may differ among workers performing the same job owing to different abilities or scheduling reasons.

U_1 = {hardware repair, data backup}, workload = $\tilde{5}$;
U_2 = {web site design}, workload = $\tilde{2}$;
U_3 = {new system development}, workload = $\widetilde{20}$;
U_4 = {new system development, web site design}, workload = $\widetilde{22}$;
U_5 = {new system development}, workload = $\widetilde{15}$.

5.2. Numerical results

The following applies the proposed assessment model to select two computer engineers suited to perform the specified task, i.e., system modification.

Step1: No conflict exists among the five tasks. All workers are candidate workers.

Step 2, 3, and 4: Table 4 lists the $\tilde{E}_{\text{CAP}}(U_i)$, $\tilde{E}_{\text{LOAD}}(U_i)$, $\tilde{E}_{\text{SIM}}(U_i)$, and $\tilde{E}_{\text{IND}}(U_i)$ for each worker. For clarity, only the central values of the triangular fuzzy numbers are listed. Table 5 lists the degree of similarity among tasks for evaluating $\tilde{E}_{\text{SIM}}(U_i)$.

Step 5: Table 6 ranks the candidate teams by suitability score. Notably, the listed scores have been defuzzified, i.e., the scores are the BNP values of the corresponding fuzzy numbers.

Step 6, 7, and 8: Table 7 ranks the candidate teams according to the BNP values of $\tilde{E}_{\text{TEAM}}$. Workers U_2 and U_4 are thus chosen/recommended to perform the given task (system modification).

Table 1. Task requirements

Criteria		system modification	new system development	data backup	hardware repair	web site design
skill	programming	e imp	e imp	b imp	not	v imp
	system analysis	m imp	e imp	not	not	m imp
	hardware	b imp	v imp	v imp	e imp	not
	network	not	not	b imp	v imp	v imp
	art design	not	not	not	not	v imp
	coordination	m imp	e imp	not	not	m imp
	leadership	not	v imp	not	not	not
manpower requirement		2	3	1	1	2

*note: imp = important, e = extremely, v = very, m = moderately, b = barely.

Table 2. Worker capability ratings

Skills	U_1	U_2	U_3	U_4	U_5
programming	normal	normal	expert	expert	expert
system analysis	low	low	good	expert	normal
hardware	expert	low	normal	good	low
network	normal	normal	good	normal	low
art design	no	expert	no	low	good
coordination	no	low	normal	good	good
leadership	low	no	normal	good	normal

Table 3. Ratings of social relationships among workers

	U_1	U_2	U_3	U_4	U_5
U_1	—	worst	poor	fair	good
U_2	worst	—	good	best	best
U_3	poor	good	—	good	worst
U_4	fair	best	good	—	poor
U_5	good	best	worst	poor	—

Table 4. Resultant individual suitability scores

Score	U_1	U_2	U_3	U_4	U_5
$\tilde{E}_{\mathrm{CAP}}(U_i)$	0.100	0.089	0.191	0.229	0.183
$\tilde{E}_{\mathrm{LOAD}}(U_i)$	0.230	0.242	0.172	0.164	0.191
$\tilde{E}_{\mathrm{SIM}}(U_i)$	0.208	0.165	0.154	0.319	0.154
$\tilde{E}_{\mathrm{IND}}(U_i)$	0.538	0.496	0.517	0.712	0.528

Table 5. Degree of similarity among tasks

Task	system modification	new system development	data backup	hardware repair	web site design
• system modification	1.000	0.429	0.292	0.286	0.459
• new system development	0.429	1.000	0.292	0.167	0.024
• data backup	0.292	0.292	1.000	0.601	0.143
• hardware repair	0.286	0.167	0.601	1.000	0.286
• web site design	0.459	0.024	0.143	0.286	1.000

Table 6. Rank candidate teams

Rank by $\tilde{E}_{\mathrm{CAP}}(U_i)$		Rank by $\tilde{E}_{\mathrm{CAP}}(U_i) \oplus \tilde{E}_{\mathrm{LOAD}}(U_i)$		Rank by $\tilde{E}_{\mathrm{CAP}}(U_i) \oplus \tilde{E}_{\mathrm{SIM}}(U_i)$		Rank by $\tilde{E}_{\mathrm{CAP}}(U_i) \oplus \tilde{E}_{\mathrm{LOAD}}(U_i) \oplus \tilde{E}_{\mathrm{SIM}}(U_i)$	
Team	Score	Team	Score	Team	Score	Team	Score
$\{U_3, U_4\}$	0.453	$\{U_4, U_5\}$	0.803	$\{U_1, U_4\}$	1.821	$\{U_1, U_4\}$	2.216
$\{U_4, U_5\}$	0.448	$\{U_3, U_4\}$	0.789	$\{U_3, U_4\}$	1.769	$\{U_4, U_5\}$	2.119
$\{U_3, U_5\}$	0.410	$\{U_3, U_5\}$	0.773	$\{U_4, U_5\}$	1.763	$\{U_2, U_4\}$	2.106
$\{U_1, U_4\}$	0.356	$\{U_2, U_4\}$	0.761	$\{U_2, U_4\}$	1.700	$\{U_3, U_4\}$	2.105
$\{U_2, U_4\}$	0.354	$\{U_1, U_4\}$	0.751	$\{U_1, U_3\}$	1.324	$\{U_1, U_5\}$	1.740
$\{U_1, U_3\}$	0.318	$\{U_2, U_5\}$	0.744	$\{U_1, U_5\}$	1.319	$\{U_1, U_2\}$	1.728
$\{U_2, U_3\}$	0.316	$\{U_1, U_5\}$	0.734	$\{U_3, U_5\}$	1.267	$\{U_1, U_3\}$	1.727
$\{U_1, U_5\}$	0.312	$\{U_2, U_3\}$	0.730	$\{U_1, U_2\}$	1.255	$\{U_2, U_5\}$	1.631
$\{U_2, U_5\}$	0.310	$\{U_1, U_3\}$	0.720	$\{U_2, U_3\}$	1.203	$\{U_3, U_5\}$	1.630
$\{U_1, U_2\}$	0.219	$\{U_1, U_2\}$	0.692	$\{U_2, U_5\}$	1.198	$\{U_2, U_3\}$	1.617

Table 7. Candidate teams ranked by $\tilde{E}_{\mathrm{TEAM}} = \tilde{E}_{\mathrm{CAND}} \oplus \tilde{E}_{\mathrm{RL}}$

Candidate Team	$\tilde{E}_{\mathrm{TEAM}}$ (BNP)
$\{U_2, U_4\}$	2.973
$\{U_3, U_4\}$	2.805
$\{U_1, U_4\}$	2.716
$\{U_2, U_5\}$	2.498
$\{U_1, U_5\}$	2.440
$\{U_4, U_5\}$	2.385
$\{U_1, U_3,\}$	2.317
$\{U_1, U_3\}$	1.993
$\{U_1, U_2\}$	1.728
$\{U_3, U_5\}$	1.630

5.3. Discussion

As shown in the first column of Table 6, if $\tilde{E}_{\mathrm{LOAD}}(U_i)$ is ignored, workers U_3 and U_4 will be assigned to the task "system modification" owing to their outstanding abilities in this area, but this choice illustrates the ratchet effect. However, workers U_4 and U_5 are chosen once the influence of workload is considered (see column 2). When workload is neglected and only $\tilde{E}_{\mathrm{CAP}}$ and $\tilde{E}_{\mathrm{SIM}}$ are considered (see column 3), workers U_1 and U_4 are selected. These results indicate that the influence of previously assigned tasks ($\tilde{E}_{\mathrm{LOAD}}$ and $\tilde{E}_{\mathrm{SIM}}$) should be considered during task assignment. A comprehensive assessment of worker suitability should consider worker abilities, social relationships, and task relationships.

In practice, the worker capability ratings and their social relationships can be obtained from HR databases. Therefore, a WfMS can automatically select appropriate performers for a given task by using the proposed matching procedure and HR databases. The proposed model utilizes existing HR information and increases workflow automation.

Although overcoming the drawbacks of person-based assignment, i.e., updating workflow definitions when workers change jobs, role-based assignment has an undesirable side effect in the form of the role resolution problem, i.e., choosing actual workers to perform the tasks assigned to a specific role. The proposed task assignment procedure in a WfMS is as follows. Step1. *Role-based assignment*: assign a task in a workflow to an organizational role. Step2. *Role instance selection*: workers suited for a particular task are selected based on the proposed assessment procedure (see Section 4.5). This procedure allows steady workflow definitions and the effective use of human resources.

6. Conclusion

This work designs a multi-criteria assessment model to solve the problem of role-based task assignment in WfMSs being inadequate for selecting actual workers to perform a given task assigned to a specific role. The assessment model evaluates the suitability of candidate workers for the task according to three criteria: capabilities, social relationships, and task relationships. After assigning a task to a role in a workflow definition at build-time, the proposed model can be used to select workers suitable for a given task at run-time. The combination of role-based assignment and the proposed multi-criteria assessment model effectively enhances the functionality of current WfMSs.

Acknowledgements

This research was supported by the National Science Council of the Republic of China under contract No. NSC 91-2416-H-009-008.

References

[1] R. E. Bellman and L. A. Zadeh, "Decision-Making in a Fuzzy Environment", *Management Science*, 17(4), pp. 141-164, 1970.

[2] G. Bortolan and R. Degani, "A Review of Some Methods for Ranking Fuzzy Subsets", *Fuzzy Sets and Systems*, 15(1), pp. 1-19, 1985.

[3] C. Bussler and S. Jablonski, "Policy Resolution for Workflow Management Systems", *Proceedings of the 28th Hawaii International Conference on System Sciences (HICSS-28)*, pp. 831-840, Wailea, Hawaii, USA, January 3-6, 1995.

[4] M. D. Dunnette, *Personnel Selection and Placement*. Brooks-Cole, 1966.

[5] D. F. Ferraiolo, R. Sandhu, S. Gavrila, D. R. Kuhn, and R. Chandramouli, "Proposed NIST Standard for Role-Based Access Control", *ACM Transactions on Information and Systems Security*, 4(3), pp. 224-274, 2001.

[6] D. Georgakopoulos, M. Hornick, and A. Sheth, "An Overview of Workflow Management - from Process Modeling to Workflow Automation Infrastructure", *Distributed and Parallel Databases*, 3(2), pp. 119-153, 1995.

[7] Y.-N. Huang and M.-C. Shan, "Policy-Based Resource Management", *Proceedings of the 11th International Conference on Advanced Information Systems Engineering (CAiSE'99)*, pp. 422-428, Heidelberg, Germany, June 14-18, 1999.

[8] G. Kappel, P. Lang, and S. Rausch-Schott, "Workflow Management Based on Objects, Rules, and Roles", *IEEE Bulletin of the Technical Committee on Data Engineering*, 18(1), pp. 11-18, 1995.

[9] A. Kaufmmann and M. M. Gupta, *Introduction to Fuzzy Arithmetic*. Van Nostrand Reinhold, 1991.

[10] F. Leymann and W. Altenhuber, "Managing Business Processes as an Information Resource", *IBM Systems Journal*, 33(2), pp. 326-348, 1994.

[11] G.-S. Liang and M.-J. J. Wang, "Personnel Placement in a Fuzzy Environment", *Computers & Operations Research*, 19(2), pp. 107-121, 1992.

[12] C. T. Lin and C. S. G. Lee, "Real-Time Supervised Structure/Parameter Learning for Fuzzy Neural Network", *Proceedings of IEEE International Conference on Fuzzy Systems*, pp. 1283-1291, San Diego, CA, USA, March 8-12, 1992.

[13] P. Milgrom and J. Roberts, *Economics, Organization and Management*. Prentice-Hall, 1992.

[14] M. J. Nash and K. R. Poland, "Some Conundrums Concerning Separation of Duty", *Proceedings of 1990 IEEE Computer Society Symposium on Research in Security and Privacy*, pp. 201-207, Oakland, CA, USA, May 7-9, 1990.

[15] W. Pedrycz, "Why Triangular Membership Functions?" *Fuzzy Sets and Systems*, 64(1), pp. 21-30, 1994.

[16] W. Rupietta, "Organization Models for Cooperative Office Applications", *Proceedings of the 5th International Conference on Database and Expert Systems Applications (DEXA'94)*, pp. 114-124, Athens, Greece, September 7-9, 1994.

[17] R. T. Simon and M. E. Zurko, "Separation of Duty in Role-Based Environments", *Proceedings of the 10th Computer Security Foundations Workshop*, pp. 183-194, Rockport, MA, USA, June 10-12, 1997.

[18] J. Y. Teng and G. H. Tzeng, "Fuzzy Multicriteria Ranking of Urban Transportation Investment Alternatives", *Transportation Planning and Technology*, 20(1), pp. 15-31, 1996.

[19] S. H. Tsaur, G. H. Tzeng, and K. C. Wang, "Evaluating Tourist Risks from Fuzzy Perspectives", *Annuals of Tourism Research*, 24(4), pp. 796-812, 1997.

[20] S. B. Yaakob and S. Kawata, "Worker's Placement in an Industrial Environment", *Fuzzy Sets and Systems*, 106(3), pp. 289-297, 1999.

[21] L. A. Zadeh, "The Concept of a Linguistic Variable and Its Application to Approximate Reasoning. Parts 1,2, and 3", *Information Sciences*, pp. 8(3), pp. 199-249, 8(4), pp. 301-357, 1975, 9(1), pp. 43-80, 1976.

[22] L. A. Zadeh, "Fuzzy Sets", *Information and Control*, 8(3), pp. 338-353, 1965.

[23] R. Zhao and R. Govind, "Algebraic Characteristics of Extended Fuzzy Numbers", *Information Sciences*, 54(1-2), pp. 103-130, 1991.

[24] M. zur Muehlen, "Resource Modeling in Workflow Applications", *Proceedings of the 1999 Workflow Management Conference (WFM99)*, pp. 137-153, Muenster, Germany, November 9, 1999.