Analyzing Social Roles Based on a Hierarchical Model and Data Mining for Collective Decision-Making Support

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***Abstract*—With the popularity of social networking services (SNSs) and the increase of users, individuals' social roles in a social network have become more and more important in terms of the recommendation of personalized services and the collective decision-making process. Usually, in an SNS system, active users may not represent the major opinions among the whole users, and most of the users' opinions may be multifarious. In this paper, we focus on analyzing and identifying users' dynamical social roles to facilitate the collective decision-making process. After introducing the social choice theory and an improved collective decision-making model, we present a three-layer model to analyze users' social roles in a hierarchical way and develop an integrated mechanism to utilize the identification of social roles to support the collective decision making. Based on a developed NetLogo-based tool, a case study for the course-offering determination with an application scenario is demonstrated to show the process of using users' social roles to support the collective decision making. The comparison experiment conducted between our method and the Delphi method shows the usefulness of our proposed method to help users achieve the decision consensus in a more efficient way.**

***Index Terms*—Collective decision making, data mining, social media, social roles, user model.**

I. Introduction

With the rapid development of emerging computing paradigms [1] and high accessibility of social networking service (SNS) which leads to an increasing complexity of the social-economic environment [2], it has become increasingly necessary to find an effective way to provide the support for the social facets of collaborative works. The collective decision-making process, which can be defined as a process that a group of individuals tries to achieve a common solution of a decision problem with several alternatives, considering their own opinions or preferences [3], is considered as an important part in a lot of conceivable human tasks [4]. It indicates that the study of decision making is necessary and important in many groupware or collaboration systems along with the high development of the Internet, electronic communication, knowledge-based economy, and information technologies [5]. In particular, the social issues [5], such as the user roles, relationships, and communities [6], have been emphasized in these systems. Thus, in this study, we focus on assisting the collective decision-making process based on the analysis and identification of users' different social roles.

"Social roles are the part people play as members of a social group" [7]. For instance, users begin to play their social roles when they join a discussing group in SNS. The identification of social roles can be viewed as the effective means to help people understand the characteristics of the network [8]. However, the social roles that users played may change dynamically in different situations [9], which may result in different decisions. Therefore, it is important to analyze users' social roles in both real world and cyber world to better understand users' requirements, which will facilitate the achievement of the decision consensus efficiently in the collective decision-making process.

In this paper, which is extended and improved from our earlier work presented in [10], we concentrate on analyzing the social roles based on a hierarchical model and data mining and develop an integrated mechanism to facilitate the collective decision-making process. In detail, following the introduction of the social choice theory and the collective decision-making model, we propose a social role analysis model, in which three layers, namely, the content layer, individual profile layer, and relation layer, are introduced to analyze the social roles in a hierarchical way. Then, a mechanism is developed to support the collective decision-making process in accordance with the dynamical identification of social roles. Based on these, we develop a NetLogo-based tool which can be utilized to simulate the collective decision making in a course offering decision-making (COD) system [11].

The rest of this paper is organized as follows. We give an overview on the related issues and works in Section II. In Section III, we briefly describe the social choice theory and a collective decision-making model. In Section IV, a three-layer model is presented to analyze users' social roles in a hierarchical way, and the dynamic identification of social roles in different layers is discussed. Moreover, an integrated mechanism to support the collective decision-making process is proposed. In Section V, based on the COD system, we design

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and implement a simulation to demonstrate the comparison between our proposed method and the Delphi method. An application scenario is discussed to show how to utilize individuals' social roles to support the collective decision-making process in Section VI. Finally, we conclude this study and give some promising perspectives on future works in Section VII.

II. Related Work

Three main issues related to this study are walked through in this section, i.e., issues of collective decision-making analysis and modeling, studies on multiagent collective decision-making systems, and analyses of social roles are addressed, respectively.

A. Collective Decision-Making Analysis and Modeling

Recently, in order to analyze the collective decision-making process, a lot of studies have been conducted [12]–[17]. Li *et al.* introduced a distributed protocol for the collective decision making [12]. Hamann *et al.* proposed a generalized approach to analyze the symmetry breaking in the collective decision-making process [13]. Nurmi described the straightforward generalizations of the solution concepts in terms of the fuzzy social or individual preference relations [14]. Gaudin *et al.* presented the analysis of collective processes in command and control activities [15]. Sánchez-Anguix *et al.* analyzed how environmental conditions affect different intrateam strategies in order to provide teams with the knowledge to select the proper intrateam strategy [16]. Cui *et al.* presented a multicriteria group decision-making approach which employed the fuzzy theory and the entropy-based method [17].

The modeling of the collective decision-making process has also been widely discussed. Zhukovskayaa and Fainzil'berg proposed a constructive interval model to make a collective decision by an independent group of experts [18]. Valentini *et al.* presented a weighted voter model which implemented a self-organized collective decision-making process [19].

B. Multiagent Collective Decision-Making Support

As for the studies on multiagent collective decision making, several models and applications have been developed to solve the existing problems and issues [20]–[27]. Li *et al.* studied the problem of collective decision making in the case where the agents' preferences were represented by CP-nets (conditional preference networks) [20]. Bosse *et al.* presented a computational model which cannot only enable the individual intentions to converge to an emerging common decision but also achieve the sharing of underlying individual beliefs and emotions at the same time [21]. O'Connell and Stearns investigated the problem of designing the mechanisms to control the collective decisions made by self-interested autonomous agents [22]. Sharpanskykh and Treur addressed how internal agent models and behavioral agent models for collective decision making can be related to each other [23]. Yu *et al.* presented an implicit leadership algorithm based on a simple purely local control law which allows all agents to follow a single rule and efficiently reach a common group decision without complex coordination mechanisms [24]. Reina *et al.* derived cognitive design patterns for collective decision making inspired by the nest-site selection behavior of honeybee swarms [25]. Fan and Su introduced the concept of "diffusion" into the multiagent system and investigated the impacts of using diffusion distances on the performance of solution synthesis in the experience-based multiagent decision making [26]. Yu *et al.* described a demonstration of a multiagent game for training students in the practice of Agile software engineering [27].

In addition, many research works have concentrated on the studies of system framework to process the multiagent collective decision making [28]–[31]. Saffre and Simaitis presented a collective decision-making framework inspired by biological swarms, which was capable of supporting the emergence of a consensus within a population of agents in the absence of environment-mediated communication [28]. Sá provided a group decision-making framework in which the agents were able to employ abductive reasoning and discuss the options toward consensus [29]. Fan and Su took 2-D perspectives to explore the use of diffusion distance and Euclidean distance in identifying "similar" experiences which can be viewed as a key activity in the process of recognition-primed decision making [30]. Vo and Li provided a generic and flexible framework to allow the concepts and results of the game theory to be more readily mapped to the reasoning and decision-making mechanisms in multiagent systems by making agents' expectations explicit [31].

C. Social Role Analysis

On the other hand, to determine different social roles, a lot of studies have been done. Research works have been conducted to confirm users' roles in the social networks [32]–[37]. Nolker and Zhou identified the key members' roles by discovering the implicit knowledge from the online communities [32]. Vanesa and Sal described a search engine for detecting the roles in a social network [33]. Gleave *et al.* analyzed the strategies for identifying social roles in the online community based on a conceptual definition of social roles [34]. Welser *et al.* improved a method for expansion and refinement of the role signatures in Wikipedia and identified other important social roles [35]. Sankar proposed a framework called "Information Wheel" to identify the roles in information systems, which was similar to a physical wheel consisting of a hub, a rim, a tire, and spokes [36]. Sarcevic *et al.* examined a particular feature of team interaction in time-critical situations, in order to identify the "job role" in supporting coordinated work [37].

Researchers also focus on the analysis and utilization of the social roles. Nair *et al.* presented a practical analysis to quantitatively evaluate different algorithms in terms of role allocation and reallocation approaches [38]. Takabi and Joshi formally defined the problem of mining a role hierarchy with minimal perturbation [39]. Molloy *et al.* advocated a two-step process of role mining with noisy data and proposed the nonbinary matrix decomposition as a solution to cleaning the user-permission relation [40].

D. Summary

Comparing with the traditional studies which mostly focus on the optimization of the decision-making process, our study focuses more on an integrated approach to utilizing the users' dynamical social roles to support the facilitation of the decision-making process. Moreover, differing with the traditional studies of social role analysis, both roles in the real world and the cyber world are classified into a three-layer-based hierarchical model. Through the social role analysis, especially the analysis of social roles based on the real world, the collective decision-making process in the social networking environments is expected to be more reasonable and efficient.

III. Social Choice Theory and Collective Decision-Making Model

In this section, we introduce the social choice theory and the corresponding processes for the support of collective decision making and discuss a model to support the collaborative design.

A. Social Choice Theory Based Processes

The social choice theory is concerned with the design and analysis of methods for collective decision making [41]. There are six topics based on the theory: preference aggregation, voting theory, resource allocation and fair division, coalition formation, judgment aggregation and belief merging, and ranking system [42].

Thus, according to the theory, in a decision-making system, such as the COD system, six main processes should be considered. The first process is to obtain users' original opinions, which aims to collect users' first decisions without other users' influence. The second one is the voting process, which lets every user evaluate other users' decisions. The third process is to calculate the weight of each user's voting, which will be utilized to calculate the voting results of all of the decisions in the second process. Specifically, considering the different importance and contribution of each user in the decision-making process, in this study, the weight of each user's voting will be calculated based on the analysis results of users' social roles during this process. The fourth one is the user grouping process, in which users will be assigned into different groups based on their voting results. The fifth one is the negotiation process, in which users will discuss on the voting results of decisions within each group or among groups. Finally, the sixth process is to rerank the voting results based on the discussing results. These processes will be repeated in a circle until a consensus decision of all of the users is made.

B. Collective Decision-Making Model

Based on the six processes discussed previously and multiagent technologies [43], the collective decision-making model is conceived to consist of four major modules as shown in Fig. 1.

1) Opinion Collecting Module: At first, we need to know all users' direct opinions and preferences as the basic data, which can be collected through the questionnaire. This module includes one process: the acquirement of original opinions.

2) Opinion Processing Module: Users' opinions may be changed by others' influence. Therefore, after obtaining users' direct opinions, the second module is to share the information among all individuals and then help them make the new decisions after being possibly influenced by other users.

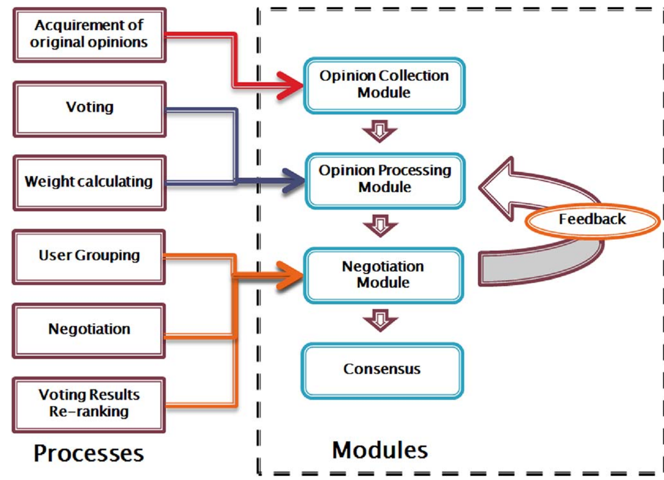


Fig. 1. Collective decision-making model.

Many methods can be used for it, such as voting and auction. Moreover, different decisions from different individuals will be assigned with different voting weights. Therefore, this module includes two processes: the voting process and the weight calculating process. In this paper, factors, such as the social roles, are taken into account in this module. After the discussions are made among the users, their opinions may be changed based on the feedback data. In order to obtain the final decision, these processes may be conducted many times.

3) Negotiation Module: In order to support the collective decision making, we need to consider not only the individual's opinion but also the whole social community's. Therefore, users are classified into different groups by analyzing their opinions, and then, they will discuss together and rerank the results. This module includes the remaining three processes: the user grouping, negotiation, and voting result reranking processes. After the discussion, we need to find a balance point to decide the final decision. Therefore, the negotiation process also needs to be repeated many times and will be sent the feedback of the related data to the opinion processing module.

4) Consensus: The last step is to achieve the consensus. After the discussions in the negotiation process, the weights of the voting results should be recalculated and reranked. If the top one opinion's weight is higher than the threshold, it can be considered as the final collective decision.

IV. Hierarchical Modeling of Social Roles for Collective Decision-Making Support

In this section, to facilitate the collective decision-making process, a three-layer model is presented to analyze users' social roles which can be viewed as an important element for the acceleration of achieving the consensus. After discussing the identification of social roles in different layers, an integrated mechanism is developed to utilize the analysis results of social roles for the collective decision-making support.

A. Three-Layer Model for Social Role Analysis

As shown in Fig. 2, based on our previous study for social role identification [44], a hierarchical model is proposed to categorize the social roles in both the real world and cyber

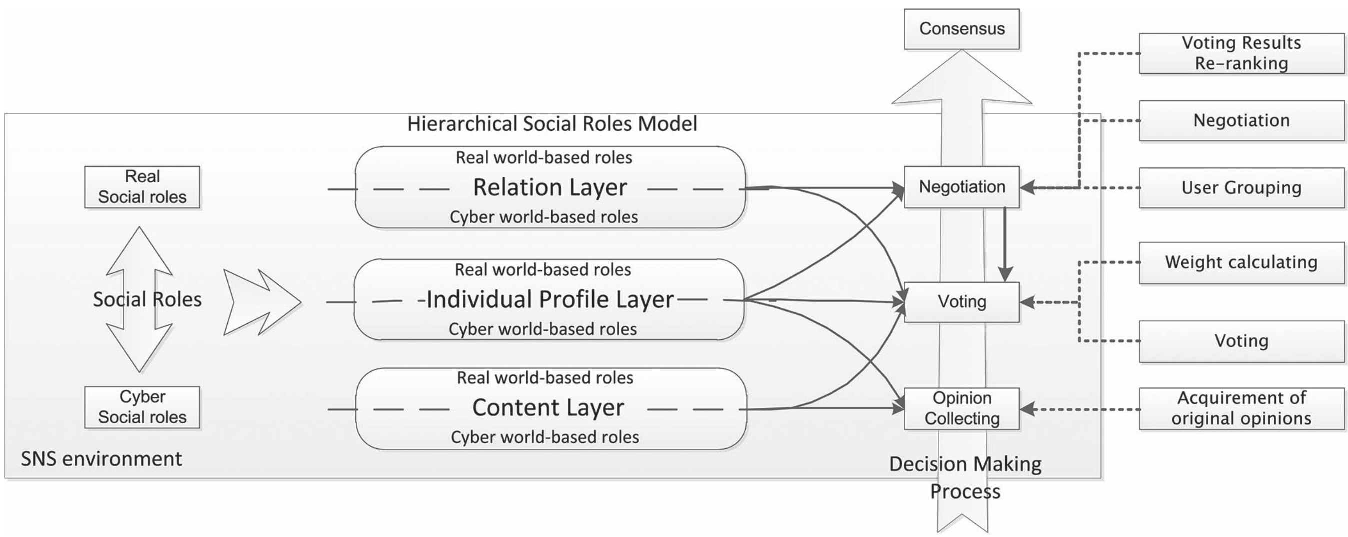


Fig. 2. Three-layer model for social role analysis corresponding to collective decision-making processes.

world into three layers: the content layer, individual profile layer, and relation layer, which can be employed to assist the different modules discussed in Section III, corresponding to the collective decision-making processes.

1) Content Layer: This layer includes the social roles which are decided by the contents along with the actions in both the real world and cyber world, such as the roles (e.g., the commissary in charge of studies) decided by the academic record in the real world or the roles (e.g., active/nonactive user) decided by the frequency of information behaviors in the cyber world. By analyzing these roles, individuals' history actions will be extracted and recorded as reference information, which may help individuals confirm their opinions finally. For example, in a COD system, before a specific user selects the courses, course-offering history record data from the commissary in charge of studies who has high academic scores, or other users who continuously keep active in the system, may provide good examples for the references. Moreover, the analysis of the roles in this layer can also be used to assist the calculation of voting weight in the decision-making process.

2) Individual Profile Layer: This layer includes the social roles which are decided by the individuals' profile. For instance, in the real world, the roles can be identified based on the gender or occupation. In the cyber world, the roles can be identified based on the user's experience in the system (e.g., the time of using the system). Note that the social roles in this layer can be used in all of the modules in the decision-making process. For example, for a course of dance, the vote from a female dancing teacher who has much experience may become more important.

3) Relation Layer: This layer includes the social roles which are decided by the relations among individuals, such as the roles based on the positions in both the real world (e.g., teacher and student) and cyber world (e.g., opinion leader and following user). Due to the characteristics of relation-based roles, in addition to supporting the calculation of voting weight, the roles in this layer are of special importance in the negation module. For example, in the negotiation process, a professor or system administrator's opinion could be considered as more important.

B. Social Role Identification

As we have discussed previously, the social roles are classified into six different types within the three layers. To assist the dynamical identification process of various social roles in different situations, we mine and analyze the personal and social data related to a group of individuals in the social networking environment. Specifically, users' different positions are utilized to identify their alternative roles.

Usually, in a certain group of people, someone may be in the "strong/high" position, while others in the "weak/low" positions, such as the roles of a professor and a student in a laboratory in the real world. Individuals who are in the "strong" position may result in the roles (e.g., professor) which will have more influence for negotiation. Therefore, based on the analysis of the personal and social data from the SNS system, we can obtain the individuals' positions, which can be utilized to identify the social roles and further help decide the voting weight in the negotiation process.

In detail, in the content layer, in order to analyze individuals' positions to identify the social roles, the related personal stream data [45] of each user are extracted and organized from the SNS environment. For example, with the mining of individuals' academic record data, we can obtain the individuals' positions within all students, which can help identify the roles in terms of their academic records in this layer.

In the individual layer, we analyze individuals' dynamical profiling built based on the behavioral data mining to analyze their different positions. For instance, the identification of the hub user [46] can be employed to analyze individuals' different positions regarding some specific issues. Specifically, the hub user is defined as the user who continuously shares and delivers information, and has influenced a lot of other users. Therefore, we can use the identification of the hub user to obtain individuals' higher positions, which will lead to the powerful roles in the collective decision-making process.

In the relation layer, the constructing of the dynamically socialized user networking model, which is built in accordance with the analysis of organized social streams [47], is used to identify individuals' different social roles. For two users i and j, the weight w_{ij} can be calculated by

$$w_{ij} = \varphi(ImR_{ij}, ExR_{ij}) \tag{1}$$

where ImR_{ij} denotes the implicit relationship while ExR_{ji} denotes the explicit relationship. The implicit relationship means those relations that cannot be perceived directly from the SNS, and the explicit relationship means those relations that can be detected directly from the SNS. Thus, we analyze individuals' different positions based on the mining of their dynamical and potential correlations within a certain group and further identify their different roles.

C. Support Mechanism for Collective Decision Making

The Delphi method, which is a consensus-building tool that allows, promotes, and encourages the involvement of all stakeholders during the evaluation framing process [48], is widely employed in the collective decision-making process. In this paper, the analysis of six types of social roles is utilized to improve the Delphi method, in order to facilitate the collective decision-making process.

According to the Delphi technique, the final decision is determined by multitimes of negotiations. In this paper, based on the hierarchical model that we have discussed previously, individuals' opinions may be influenced by the social roles categorized in three layers, including the real-world-based role δ_r and the cyber-world-based role δ_c in the content layer, the real-world-based role θ_r and the cyber-world-based role θ_c in the individual profile layer, and the real-world-based role ϑ_r and the cyber-world-based role ϑ_c in the relation layer.

Using the COD system as a case study, let $C = \{c_1, c_2, c_3, \ldots, c_n\}$ be a set of courses in the system, where n is the number of the courses. Our main purpose is to gather individuals' decisions in order to confirm the preference degree list P for all of the courses. The number of users is m. The procedure of the support mechanism is shown as follows.

Step 1) For each course i, considering each user k's social role influence S_{R1}, which is based on the roles in the content layer and individual profile layer, the evaluation value can be calculated as follows:

$$d_{ik} = F(S_{R1}, e_{ik}) \tag{2}$$

where $k = 1, 2, \ldots, m$. e_{ik} is defined as the user's evaluation, and it can be calculated as follows:

$$e_{ik} = \begin{cases} (0,1) & \text{if the user has given evaluation} \\ 0 & \text{else.} \end{cases} \tag{3}$$

The social role influence parameter S_{R1} can be calculated as follows:

$$S_{R1} = \alpha(\delta_r + \delta_c) + (1-\alpha)(\theta_r + \theta_c) \tag{4}$$

where $\alpha \leq 1$. The evaluation results can be recorded in a matrix as follows:

$$\begin{bmatrix} d_{11} & d_{12} & d_{13} & \ldots & d_{1m} \\ d_{21} & d_{22} & d_{23} & \ldots & d_{2m} \\ d_{n1} & d_{n2} & d_{n3} & \ldots & d_{nm} \end{bmatrix}.$$

For each course i, in each line of the matrix, calculate the average value $\overline{d}_i$ and variance value v_i as follows:

$$\overline{d}_i = \frac{1}{m}\sum_{k=1}^{m} d_{ik} \qquad i = 1, 2, \ldots, n \tag{5}$$

$$v_i = \sqrt{\frac{1}{m}\sum_{k=1}^{m}(d_{ik} - \overline{d}_i)^2} \qquad i = 1, 2, \ldots, n. \tag{6}$$

Step 2) Feedback the results in *step 1* to all users. After the negotiation, in the new round of evaluation, for each course i, considering the social role influence S_{R2}, which is based on the roles in the individual profile layer and relation layer, the evaluation value can be calculated as follows:

$$d_{ik}{}' = F\left(S_{R2}, e_{ik}{}'\right). \tag{7}$$

The social role influence parameter S_{R2} can be calculated as follows:

$$S_{R2} = \beta(\theta_r + \theta_c) + (1-\beta)(\vartheta_r + \vartheta_c) \tag{8}$$

where $\beta \leq 1$. The evaluation results in the new round can be recorded in a matrix as follows:

$$\begin{bmatrix} d_{11}{}' & d_{12}{}' & d_{13}{}' & \ldots & d_{1m}{}' \\ d_{21}{}' & d_{22}{}' & d_{23}{}' & \ldots & d_{2m}{}' \\ d_{n1}{}' & d_{n2}{}' & d_{n3}{}' & \ldots & d_{nm}{}' \end{bmatrix}.$$

For each course i, in each line of the matrix, calculate the average value $\overline{d}_i'$ and variance value v_i as follows:

$$\overline{d}_i{}' = \frac{1}{m}\sum_{k=1}^{m} d_{ik}{}' \qquad i = 1, 2, \ldots, n \tag{9}$$

$$v_i{}' = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left(d_{ik}{}' - \overline{d}_i{}'\right)^2} \qquad i = 1, 2, \ldots, n. \tag{10}$$

Step 3) We assume that, after l times of loops, it achieves that the variance value $v_i^l \leq \epsilon$, where ϵ is the threshold given in advance, i.e., repeat ***step 2*** until the variance value $v_i^l \leq \epsilon$. The final matrix of the evaluation results is

$$\begin{bmatrix} d_{11}{}^l & d_{12}{}^l & d_{13}{}^l & \ldots & d_{1m}{}^l \\ d_{21}{}^l & d_{22}{}^l & d_{23}{}^l & \ldots & d_{2m}{}^l \\ d_{n1}{}^l & d_{n2}{}^l & d_{n3}{}^l & \ldots & d_{nm}{}^l \end{bmatrix}.$$

Step 4) Calculate the average value $\overline{d}_i{}^l$ for each course as follows:

$$\overline{d}_i{}^l = \frac{1}{m}\sum_{k=1}^{m} d_{ik}{}^l. \tag{11}$$

Finally, we can have the result list P as follows:

$$P = \left\{\overline{d_1}^l, \overline{d_2}^l, \overline{d_3}^l, \ldots, \overline{d_n}^l\right\}. \tag{12}$$

V. Application to COD and Simulation Experiment

In this section, we introduce a case study of the course-offering determination (COD) system [11] and discuss the simulation experiment which demonstrates a comparison between our proposed method and the Delphi method.

A. COD

We assume the COD system integrated with a social network application (such as a Twitter-like system, e.g., Status-Net [49]) to allow the students to publish comments, discuss with the professor and/or other students, and vote/negotiate about the courses which may be offered in the coming semester. This will assist students to choose the courses and help the professors and university staff to make the teaching plans.

Having a lot of different courses to choose, students may feel difficult about how to select. Therefore, any reference information or chance to discuss with other students will be helpful to them. Because of the different characteristics among the system users, when making the final decision, it is not possible for all students, professors, and staff to have the same voting weights. We try to use our method to benefit all students, professors, and staff for the facilitation of decision making in this COD process.

Based on the aforementioned discussion, considering the influence of social roles, two major functions are implemented into the system.

1) Providing Reference Information: Since it is sometimes difficult for people to know their own needs clearly when they face decision making, through this function, our system will provide an interface for users to collect their direct opinions. Then, according to filtering of the social-role-based historical data, our system will provide the users with the useful information (such as the historical decision data in the previous semester) as the reference to help them determine their opinions.

On the other hand, in the negotiation process, since the number of users is large, it is difficult to check all of their opinions. Therefore, this function can also provide the users with the related information from other users by analyzing their social roles.

2) Collecting Opinion: Since people may sometimes have different positions in the real world and cyber world, by this function, based on the social role analysis, the users will be assigned with different voting weights, in order to make the voting process more effective and efficient.

In this system, in addition to the voting process, since it is often difficult to reach the consensus when people have different opinions, the negotiation process is needed. Therefore, when a negotiation process begins or becomes complex, we can use the voting weight in this function to support the negotiation process.

In order to test the system with our methods, we used NetLogo [50] to integrate and implement these functions, which is a multiagent programmable modeling environment.

B. System Simulation With NetLogo

We simulate a course offering process with two different decision-making methods, namely, our proposed method and the Delphi method, as shown in Fig. 3.

1) Simulation Setting: According to the mechanism and the COD system environment that we have discussed previously, at first, as the general setting, we set up two basic parameters: num-groups (the number of plan groups) and num-individuals (the number of users who are involved in a specific decision-making process). In this case study, the plan groups represent a set of courses, and the individuals include the students, professors, administrators, etc.

In order to control the simulation, we set up other three parameters, namely, the change-rate, vote-rate, and stop-setting. Since the individuals may not change their decisions in each negotiation, we set the change-rate to decide the probability of decision change. Similarly, we set up the vote-rate to adjust the probability whether the individuals change their opinions. At last, the stop-setting is responsible for setting the threshold to stop the simulation. In this case study, the variance value is employed as the threshold to reach the consensus.

In addition to these parameters to control the simulation process of the Delphi method, as for the social role setting, two other sets of parameters are utilized to control our social-role-based method. One set of parameters is the alpha-set and beta-set. These two parameters are used to adjust the impact factors α and β which we mentioned in ***step 1*** and ***step 2*** in Section IV. According to the social analysis which we have discussed in Section IV, another important set of parameters is the role ratio setting, which represents the composition of social roles in terms of the six types. For instance, the "Rlayer-R-high-scale" indicates the ratio of individuals who have a "strong/high" position in the relation layer of the real world. Based on our methods, the ratio of the roles can be identified among a total of six types (including each layers' real/cyber roles) within the three layers.

2) Simulation Process: After setting up all of the parameters and choosing the running mode (e.g., the Delphi method mode or the social-role-based mode), the simulation begins from ***step 1*** by pressing the button "setup," after which all of the users get into the initial state that they have finished their first round voting. Then, we click the button "go once" to push the negotiation process, i.e., every time the button "go once" is clicked, one new round of negotiation will be conducted, and the result will be demonstrated in the screen. We use the icons of "person" and "box" to simulate the individuals and the plan groups. As shown in Fig. 4, after one negotiation, each user will have a tendency to each plan group, and the average score of each plan group will be shown under each "box." For a specific user, the line that connected him/her to one group indicates his/her highest tendency among all of the groups. This process will be repeatedly conducted, until the final consensus is achieved, and the total negotiation times will be shown at the top of the screen.

3) Comparison and Evaluation: With the simulation results, we conduct the evaluations to compare our social-role-based method with the Delphi method in two experiments.

First, we conduct the comparison experiment to evaluate the performances under different numbers of plan groups and users. In detail, the following three cases are utilized to evaluate the performances of both methods: 1) 6 plan groups with 60 users; 2) 12 plan groups with 60 users; and 3) six plan groups with

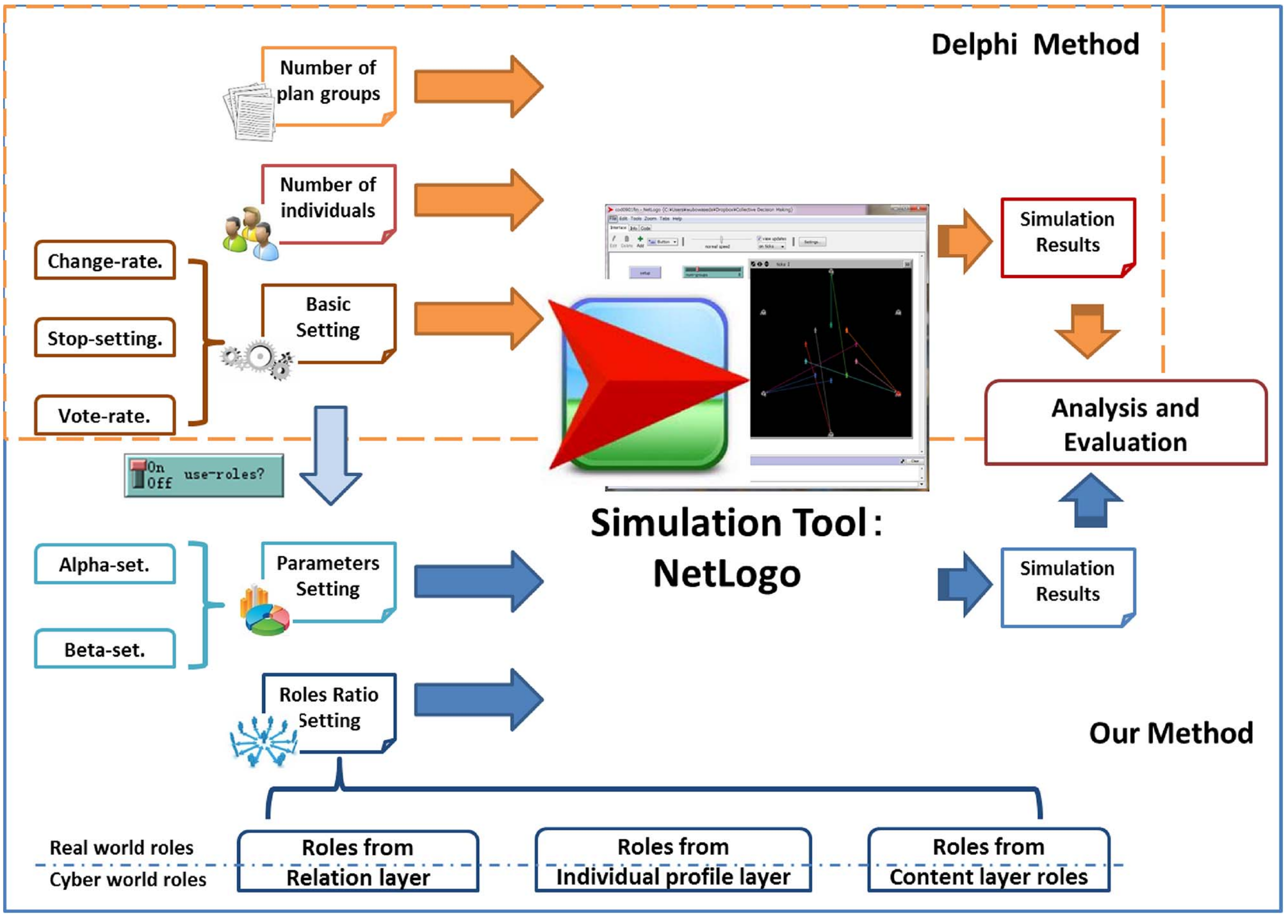


Fig. 3. Workflow of the simulation environments based on our proposed method and the Delphi method.

30 users, which simulate three different situations, namely, a few plan groups to many users, many plan groups to many users, and a few plan groups to few users. Each case was repeated ten times for the negotiation using each method. The results are shown in Fig. 5.

On the other hand, we evaluate the performances of both methods under different thresholds to reach the consensus. In detail, based on a large number of experiments using our developed tool, three thresholds of 0.04, 0.45, and 0.05 are selected for the comparison experiment. Likewise, we conducted ten times under each threshold for both methods, respectively. The results are shown in Fig. 6.

4) Discussion: According to the two experimental results shown in Figs. 5 and 6, our method averagely has fewer negotiation times (nearly half) comparing with the Delphi method, which indicates that people may reach the consensus more quickly when using our social-role-based method in a collective decision-making process. As shown in Fig. 5, under the same setting (vote-rate $= 0.5$, change-rate $= 0.5$, and stop-setting $=$ 0.05), our method performs much better in case 1 comparing with the other two cases. It indicates that our method would lead to better results in the situation when many users face a few of the plan groups.

On the other hand, by comparing the results shown in Fig. 6, a smaller stop-setting value will lead to a better result, which means that, in our method, the stricter the consensus requires, the better result we may obtain.

VI. Application Scenario

We describe a scenario to show the identification process of the social roles and how these social roles are utilized to support the collective decision making.

Taking a specific user John as an example, we assumed that he and 30 friends in the same class have used the system before and have provided enough profiling data (e.g., the data which are possibly collected from their school, including their name, age, grade, test scores, etc.) in this system. Usually, John and his friends need to decide their decisions to choose the courses even if they do not know about these courses. Using our proposed method, the system can identify John and other related users' social roles by organizing and analyzing their personal data, which can further help the system to select and provide useful historical data about the courses to John as the reference information.

For example, after identifying John as a student by analyzing his personal data and social activities, the system may show the course-offering record in the previous semester from another student who plays a similar role (such as the student who has a similar academic record) to John as the reference information. This information may help John and his friends to confirm their decisions.

Then, John and his friends need to give their opinions and, if they like, give their evaluations to all of the courses. In this process, according to their different social roles, their voting weights may be different. It will be the same in the next

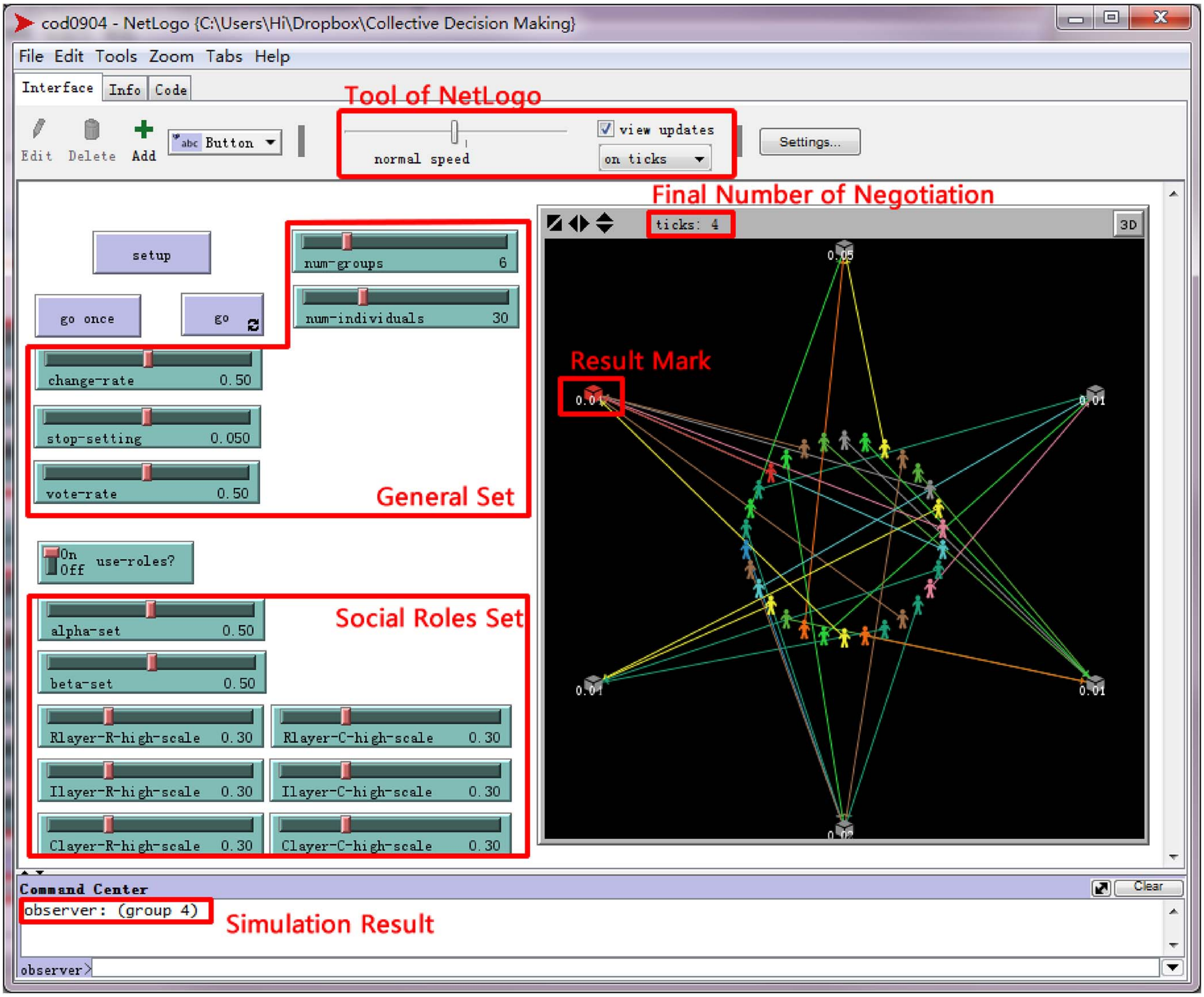
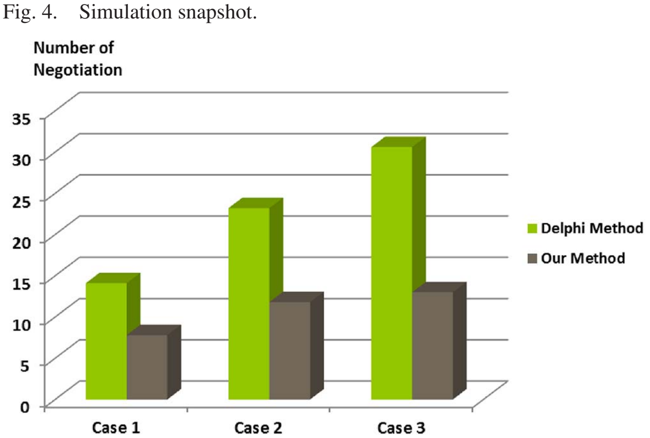
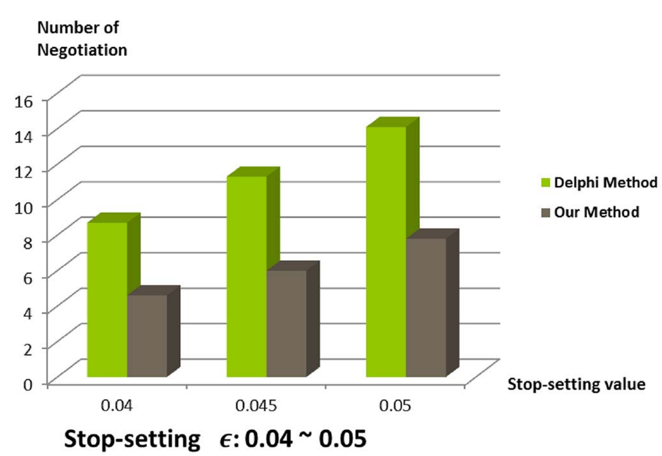


Fig. 4. Simulation snapshot.



Case 1	6 groups, 60 users	vote-rate	0.5
Case 2	12 groups, 60 users	change-rate	0.5
Case 3	6 groups, 30 users	stop-setting	0.05

Fig. 5. Simulation results with different case settings.



vote-rate	0.5	num-group	6
change-rate	0.5	num-indiviuals	60

Fig. 6. Simulation results with different stop-settings.

negotiation process. The voting weights will also be used when the consensus cannot be reached according to all of the evaluation results. In the negotiation process, John and his friends need to discuss together and then revote and evaluate the courses, until most of the users reach the consensus. Meanwhile, since the negotiation process may become complex, based on their social role analysis results, the system can send the related information, such as the similar users' opinions, to them for the reference.

As discussed previously, the key point is to calculate the voting weight for each user aided by analyzing the social roles. For instance, when re-evaluating a course, the student who used to be a commissary in charge of studies in the real world and a discussing initiator in the cyber world will have a higher voting weight than John, as he is a normal student and always acts as an audient during the discussions.

Therefore, for John and other related users, after using the modules in the voting and negotiation process repeatedly, they may finally reach the consensus with the social role analysis support. Comparing with the general collective decision-making process, in this study, we focus more on the users' social roles in both the real world and cyber world and use them to support the decision-making process. Using this approach, users can reach the consensus more quickly rather than only considering the voting results.

VII. Conclusion

In this paper, following the introduction of the social choice theory and a collective decision-making model, we have proposed an integrated method to support the collective decision-making process based on the analysis of individuals' social roles.

First, we have proposed a model of collective decision making based on the social choice theory. Then, we have presented a three-layer model of social roles for the collective decision-making support and described the identification of social roles in these three different layers, respectively. Based on these, an integrated mechanism was proposed and developed to support the collective decision-making process aided by analyzing users' social roles in both the real world and cyber world. As a case study, we have introduced the COD system and developed a NetLogo-based tool to demonstrate the negotiation process using our proposed social-role-based method and the Delphi method, respectively. The evaluation experiments showed the effectiveness comparing with the traditional method. Finally, an application scenario was presented to show how the enhanced system can support the collective decision-making process by analyzing users' social roles.

In summary, in this paper, we have presented and developed the following:

1) a three-layer model of social roles, which can provide a means to categorize the social roles in both the real world and cyber world for the collective decision-making support;
2) an integrated mechanism to improve the efficiency of the collective decision-making process by analyzing the social roles;
3) a NetLogo-based tool to simulate the negotiation process, which can be utilized to demonstrate and compare different decision-making methods.

As for our future work, we will improve the design and implementation of our proposed methods and related algorithms. We will conduct more experiments to evaluate the improved method and system as well.

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