Identification of the Virtual Organization Breeding Environment Based on the Cooperation Network

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Abstract. Current studies argue that through building the virtual organization breeding environment one can quickly find partners and create a virtual enterprise. The creation of the virtual organization breeding environment requires its own social capital to satisfy some social requirements, but such researches are few This paper, based on complex network theory, proposes a new method to identify the virtual organization breeding environment, which consists of four steps: first is to build the cooperation network from the history of cooperation between enterprises, then is to translate social requirements of the virtual organization breeding environment into structural characteristics, next is to establish the problem model, and final is to design the algorithm of searching for sub-networks (namely virtual organization breeding environments) in the cooperation network, which must meet specific structural characteristics. The proposed method in this paper is based on practical cooperation networks, and therefore is a good guidance to the creation of the virtual organization breeding environment.

Keywords: Cooperation Network; Virtual Organization Breeding Environment; Complex Network; Community Identification

1 Introduction

Afsamanesh et al. argued that in a virtual organization breeding environment (VBE) it was far less costly and much more effective to quickly build a virtual enterprise (VE) [1]. According to their theories, the planner could select its partners primarily from VBE members; only when there is a lack of skills or capacity inside the VBE, enterprises can be recruited from outside [2].

Swierzowicz et al. introduced the concept of social requirements for VBEs and utilized it in a case study to check if it was feasible to create a VBE among 10 steel manufacturers [3]. They concluded that some future work should be done, including developing algorithms to identify sub-networks that fulfill a given set of social requirements, within a given network of organizations [3].

This paper assumes that the emergence of the VBE is the result of the voluntary, participatory gathering of some enterprises [3]. In the past these enterprises have ever cooperated with each other for a long time, so the history of cooperation between them can provide a clue to identify the VBE. This paper proposes a method based on practical cooperation networks in which there are some enterprises that tie together closely and may consist of VBEs.

This paper modifies social requirements put forward by Swierzowicz et al. and translates them into structural characteristics which VBE members should satisfy. Then based on complex network theory, this paper suggests that the problem of identifying virtual organization breeding environments can be changed to the problem of detecting communities in the complex network.

The paper is organized as follows. In section 2, the method based on the cooperation network is presented in detail. In section 3, this method is applied to a case to demonstrate its value. Section 4 is a discussion and section 5 concludes the paper.

2 A New Method Based on the Cooperation Network

2.1 Building the Cooperation Network

The cooperation network can be depicted as a graph $G = (V, E)$, which consists of a set of nodes, denoted as V, and a set of links (also called arcs or edges), denoted as E [4]. In the social science field, a node is often referred to as an actor (that is an enterprise), and a link, is an ordered pair (i,j) representing a relationship from node i to node j.

A graph can be represented by a matrix M = (w_{ij}). If there is a link from node i to node j, w_{ij} is equal to 1; otherwise 0. In this paper, the matrix M is symmetrical (that is $w_{ij} = w_{ji}$) and there is a reciprocal relationship between node i and node j. In this situation, the value of wij or wji means the times of actor (enterprise) i and actor (enterprise) j cooperates.

The first step to build the cooperation network is to investigate the history of cooperation between enterprises from newspaper and websites. Such data should be collected as project names, years, participating enterprises and activities undertaken by them.

Then, data can be represented by a matrix in which the rows are all projects and the columns are all enterprises. Each cell of the matrix describes if an enterprise participated a project. If yes, this cell equals 1; otherwise 0. Enterprises are categorized by their primary activities in the cooperation (that are their core competences) and coded. For example, enterprises usually undertaking design are coded as G1, G2, and G3 …

It is often the case that network researchers, who see the world in "relational" terms, turn above matrix into an actor-by-actor relational matrix [5]. In this actor-by-actor matrix, each cell measures how many times pairs of actors were co-present at the same event [5].

Next is to turn such matrix to the cooperation network and Fig. 1 shows one sample. In this cooperation network, types of nodes represent enterprises' categories, for example rectangles for designers. Size of nodes indicates strength of enterprises' core competences, and thickness (also known as weights) of links indicates times of cooperation.

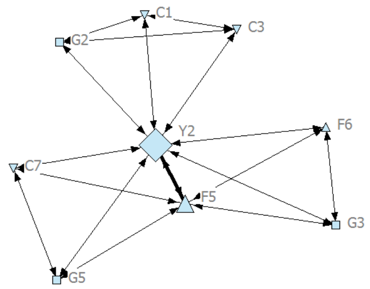

Fig. 1. The cooperation network

Structural characteristics to measure networks offer as follows:

The Degree $\deg(v)$ is the number of nodes that the node v is connected to [6]. High degrees usually indicate high levels of being active and wide social influence [7]. In Fig. 1, nodes with high degrees have large size.

The distances between nodes in a network may be an important macro-characteristic of the network as a whole [5]. In this paper, the (geodesic) distance $d_G(s,t)$ is the number of links in the shortest possible walk from node s to node t [5].

The diameter of a network is the largest (geodesic) distance in the (connected) network.

$$diam = \max_{s,t \in G}\{d_G(s,t)\} \tag{1}$$

2.2 Social Requirements and Corresponding Structural Characteristics of the Network

According to Camarinha-Matos et al., the VBE is an association of organizations and their related supporting institutions that have both the potential and the will to cooperate with each other through the establishment of a "base" long-term cooperation agreement and interoperable infrastructure [8]. When one of its members identifies a business opportunity, this member selects a subset of organizations to form a VE/VO [8].

A VBE is regulated open and have a controlled boarder, namely at any time new members can join the VBE by complying with its general operating principles [1]. Afsamanesh et al. argued that there may be different levels of membership, but in this paper, the VBE specifies tight members.

Swierzowicz et al. suggested that social requirements be used to define structural characteristics of a network and then be used to check its social capital [3]. They also noticed that social requirements are usually at a higher level of abstraction, and therefore, a "translation" between social requirements and structural characteristics of the network is usually required [3].

Swierzowicz et al. proposed a set of social requirements that are common to all VBEs, such as the size, the interconnectedness of members, and the distance between members for fast and least mediated communication while forming VO [3]. This paper assumes that the emergence of the VBE is the result of the voluntary, participatory gathering of some enterprises [3]. Under this situation, social requirements can be modified to:

- Core competences of members complement each other, and the number of members owning the same core competence is more than one;
- Members have ever cooperated with each other;
- Times of cooperation is larger than a specific value.

The VBE in the cooperation network G can be depicted as a sub-network $VBE = (V_{vbe}, E_{vbe}) \subset G$, in which V_{vbe} represents all members in the VBE and E_{vbe} represents relationships between members.

In the cooperation network, all participating enterprises in a project form a clique in which each node is the neighboring node of others. So this paper argues that, if a node is one member of the VBE, its neighbors in this clique may also be members of the VBE. Table 1 shows above social requirements and corresponding structural characteristics of the network.

- The size of VBE is greater than or equal to m if types of required nodes (namely required core competences) equal to m.
- The diameter of VBE is 1 because members in the VBE form a clique.
- The weights of all links are larger than a specific value.

Table 1. Social requirements and corresponding structural characteristics of the network.

	Social requirements	Structural characteristics
Size	Core competences of members complement each other, and the number of members owning the same core competence is more than one	$size(VBE) \geq m$ and $\sum_{x \in VBE} type(x) = m$
Distance	Members have ever cooperated with each other	$diam(VBE) = \min\{\max_{s,t \in VBE} d_{VBE}(s,t)\}$ $=1$
Interconnectedness	Times of cooperation is larger than a specific value	$\underset{s,t \in VBE}{w_{st}} > f$

The specific value f is computed as the following:

First is to sort weights of all links in the cooperation network from large to small, next is to select the specific weight, that is, the sum of weights locating before it and itself is larger than 80% of the total.

2.3 The Problem Model

In the cooperation network $G = (V, E)$, the node $u \in V$ is designated as the start node, then subsets (sub-network) $X \subset G$ satisfying the following structural characteristics can be searched from it.

$$\begin{cases} size(X) \geq m, \sum_{x \in X} type(x) = m \\ \underset{s,t \in VBE}{w_{st}} > f \\ diam(X) = \min\{\max_{s,t \in X} d_X(s, t)\} = 1 \end{cases} \tag{2}$$

If X exists, it would be the VBE.

If an enterprise participates many projects, the degree of the node representing this enterprise in the cooperation network would be very high. While a VBE exists, it can be concluded that this enterprise must be one member of the VBE. So this paper searches the subsets X from such node.

2.4 Algorithm

The identification of the VBE is very similar to community detection in complex networks. Communities within the network can loosely be defined as subsets of nodes which are more densely linked, when compared to the rest of the network [9].

The problem of community detection has been the subject of discussion in various disciplines [9, 10]. Costa reported a simple and powerful hub-based community finding methodology, especially aiming at those networks in which nodes organized around hubs into communities [11]. Here, a hub referred to a node in a network exhibiting high degree [11].

The identification of the VBE does not need to partition the cooperation network into communities, but rather search for subsets that satisfy structural characteristics in (2). However, Costa's methodology is still a good reference.

While identifying the VBE, first is to get nodes $\{u_i \mid u_i \in V\}$ in the cooperation network that have high degrees, next is to check iteratively if there is subsets X that includes u_i and satisfies structural characteristics in (2). Above algorithm is shown as the following:

```
program
  put the nodes that have higher degrees than the
average in {u_i | u_i ∈ V}
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    compute the specific value f;
    begin traversing u_i
      Y = φ
      put the nodes that are neighbors of u_i in Y = {y_j}
      begin traversing y_j
        remove those nodes from Y whose links with u_i are
  lower than f
      end
      begin searching cliques Xi in u_i ∪ Y
        if  Σ_{x∈Xi} type(x) = m
          X = Xi
          output X
      end
    end
  end
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3 Case Study

The production mode in the heavy equipment manufacturing industry is usually order-to-make, and in order to respond to business opportunities agilely the system integrator must unite some independent enterprises to form a temporary alliance (that is the VE).

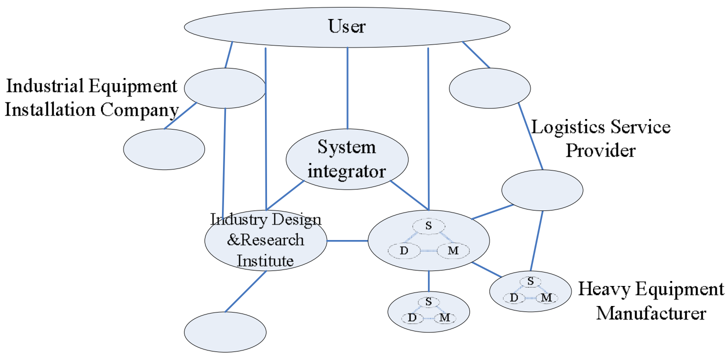

Fig. 2. The value chain

Fig. 2 shows the value chain of the heavy equipment manufacturing industry. In this value chain there are system integrators, industry design & research institutes, heavy equipment manufacturers, logistics service providers, industrial equipment installation companies and users, which have different core competences. After a period of cooperation, some of them linked very closely and may have the potential and the will to establish the VBE.

3.1 Data Collection and Processing

CDCM is one kind of products of the heavy equipment manufacturing industry, and authors in this paper collected data of 11 products manufactured from 2006 to 2009 in China, which included 29 units (each product may have more than one unit). Such data is collected as project names, years, participating enterprises and activities undertaken by them.

Because these projects attract many enterprises to participate, their cooperation usually be reported in the newspaper and they also advertise their work in their own websites. Thus, it is not difficult for the authors to collect data from the Internet.

The cooperation network generated from above data is shown in Fig. 3, which has 42 nodes. Weights of links between nodes represent times of cooperation.

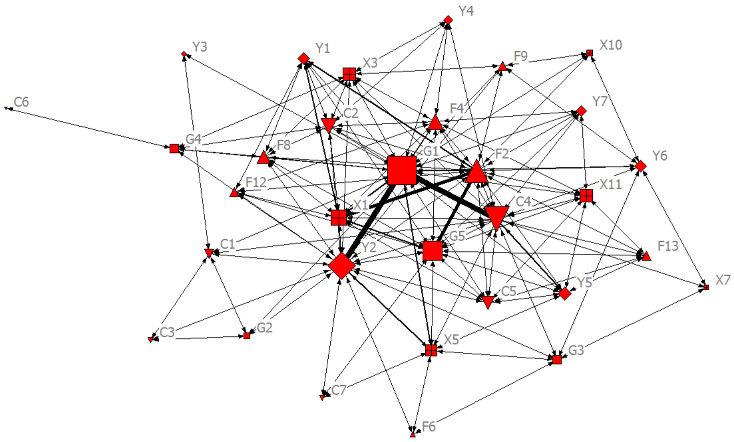

Fig. 3. The generated cooperation network

System integrator: X1, X3, X5, X7, X10, X11
Industry design & research institute: G1, G2, G3, G4, G5
Industrial equipment Installation Company: Y1, Y2, Y3, Y4, Y5, Y6, Y7
Heavy equipment manufacturer (China): C1, C2, C3, C4, C5, C6, C7
Heavy equipment manufacturer (Other countries): F2, F4, F6, F8, F9, F12, F13

3.2 Results

In Fig. 3, nodes that have degrees above the average are G1, Y2, F2, C4, G5, X1, F4, C2, X5, Y1(from large to small). Putting them in $\{u_i \mid u_i \in V\}$ and computing with the algorithm in 2.4, results show that there is not a sub-network (subsets) that satisfies structural characteristics in (2). But there exist 6 would-be VBEs.

Fig. 4 shows these 6 would-be VBEs, and the reason why they cannot satisfies structural characteristics in (2) is that the number of types of nodes in them do not achieve m. These 6 would-be VBEs overlap, and G1, X1 and F2 are the nodes that are shared the most. The authors compare these 6 would-be VBEs through computing their densities, which are 2.8333, 3.1667, 3.6667, 3.1667, 3.1667 and 3.5 separately. It is found that the possibility of 3 to develop into a true VBE is greatest.

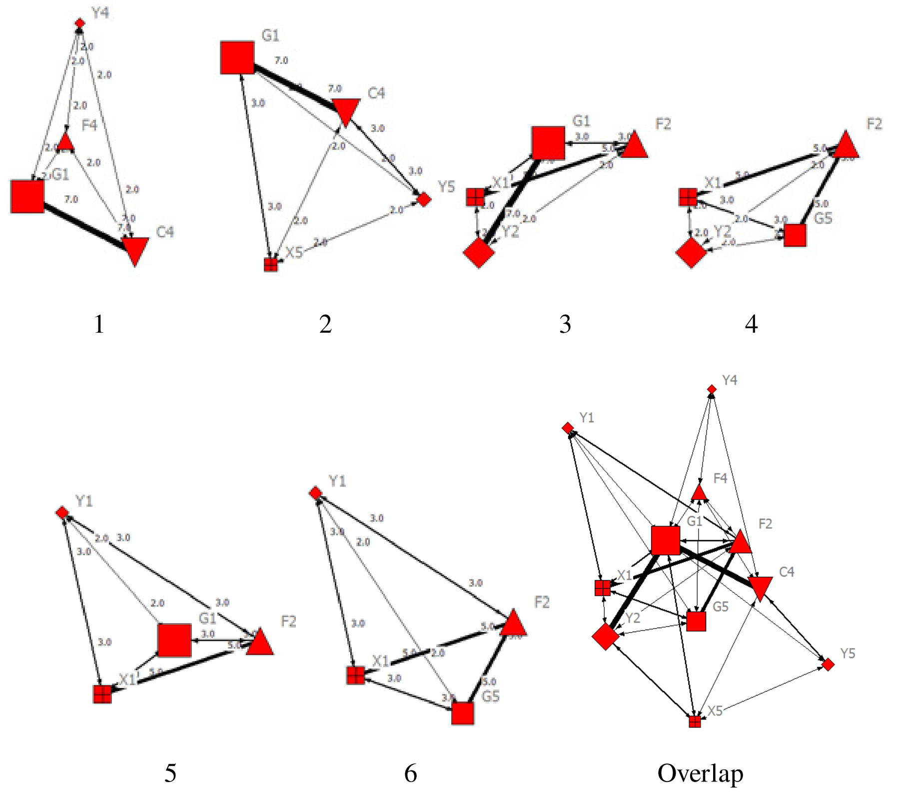

Fig. 4. The would-be VBEs

4 Discussion

In the case study, no sub-networks satisfy all social requirements; this is because Chinese companies are taking place foreign companies to become system integrator gradually. At first, users ran fast in this competition. Because of user preference and the limitation of the location, there is little possibility that enterprises cooperated again in the next project, thus resulted in that enterprises could not aggregate.

Under this situation, the requirement of the size can be relaxed, and sub-networks that satisfy other requirements can be found and they form original VBE. Then enterprises that enable the VBE to satisfy all social requirements should be attracted to join the VBE.

In this paper, the VBE specifies tight members. That is, tight members must be found first, and they form original VBE, then loose members can be attracted into the VBE. When there is a lack of skills or capacity inside the VBE, enterprises can be recruited from outside [2]. After that, if they want, they can join the VBE.

In the case study, Industry design & research institutes and large Chinese heavy equipment manufacturers grow up slowly and compete with users, so enterprises aggregate around these hubs. In the cooperation network in Fig. 3, because the node of G1 is large than others due to stronger core competences, it is suggested that it can lead the VBE to recruit new members.

5 Conclusion

This paper proposes a method based on the cooperation network, which can help the VBE planner identify sub-networks so that it develops the VBE. Now this method is applied only to the situation that VBE is the result of the participatory gathering of voluntary enterprises [3], other situations such as the creation of a VBE by a third authority [3] needs future study.

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