An Agent-mediated Approach to Promote Knowledge Sharing Through Enterprise Social Networks

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Abstract
Broadening adoption of social network tools within the enterprise suggests a new and valuable source for insight into the social structure through organizations. While online social media tools are being evolved by enterprises in recent years, the social media are used much for knowledge sharing. This paper focuses on how enterprise social network builds within and between the departments and utilize an agent-based model of social networks to clarify employees with critical network positions who other employees trust to them for receive knowledge. The structure of the paper is: first, the concept of the social network and trusting are described in the social network environment with effective knowledge sharing construct through the enterprise social network. Next, the paper presents complex network models which be used for agent based simulation. Finally, the last part investigates the agent based model to impact knowledge recipient trust on sharing knowledge through the enterprise social networks. Our results show the position of critical employees in the network and network with high trust between employees keeps close social proximity to people who actively share knowledge.

Categories and Subject Descriptors
Management, Human factors, Measurement, Performance, Theory, Verification

General Terms
Management, Measurement, Performance, Design, Human Factors

Keywords
Agent-based modeling, Social Network, Enterprise Social Network, Trust, Knowledge Sharing

1. Introduction
The concept of organizational knowledge as an important strategic asset has been promoted by academic researchers and organization theorists (for example see: [1; 2; 3; 4]). Many firms and empirical studies have been exploring the field of knowledge management (KM) to support competitive advantages [5; 6; 7].

Businesses spend resources to develop KM systems [8], but studies indicate that less than 25% of KM projects meet their promises and achieve significant performance impact [9; 10; 11]. Other empirical research based on a consulting firm report in the United States emphasizes that only 8.6% of the knowledge repositories capacity are useful and relevant to the organizational problems [12]. Also, firms lose their valuable knowledge and experiences because of losing critical employees and retiring them from the organizations. On the other hand a theoretical survey shows 61 percent of managers believe social networks can improve knowledge sharing within their organizations and improve the matching degree between the problems to the answers [6]. Beside, practical research on knowledge sharing within organizations by Krauthammer indicated 73% of people share knowledge frequently through the social network, whereas 30% of knowledge originated from the outside of the close network in the department [13]. This poses challenges to the research community: which nodes represent critical position in the social network for sharing knowledge and how these positions created in the social network?

While different online social media tools are being evolved by enterprises in recent years, knowledge network is developed as a new system for knowledge sharing supported by "*enterprise social network*". An enterprise social network (ESN) is defined as an electronic social network within a firm which makes a suitable and safe environment for social interactions between employees and knowledge sharing among employees. The social networks have been developed within firms in the recent years. There are more opportunities for partnering across geographic barriers. Knowledge is created and distributed at massive rates. One of the main issues which important for companies is to use the enterprise social network as sharing system while the principal roles of the internal social media are to facilitate knowledge sharing within employees. The social network fosters social relations to support communication and flow of knowledge among the users. The communications express as a main issue for sharing and creating organizational knowledge. The main challenge is to identify the main important positions in the network for facilitating communication between employees.

Agent-based modelling approach is a new mechanism for analyzing social systems. Agent based simulation of complex networks is used to describe interactions in many real world

systems, including economic, biological and social systems. Understanding a social system needs more than an understanding of the individuals that existing in the system. It also requires understanding how the individuals interrelate with each other, and how the outcome can be more than the sum of the parts. Agent based modeling is a very well appropriate method for modeling and recognizing how individual members (employees) behave, and how the interaction of these employees can lead to improved knowledge sharing.

Thus, This paper presents an agent-based social network model within firms to determine a comprehensive view of trust through the participatory social network and investigating the knowledge sharing in the enterprise social network . The research use agent model to generate a social network within organization and analyze the dissemination of knowledge through the network.

2. Social Network

The term "network" can be understood to make relationships among all participants, where individuals, groups and also groups of firms, communities and societies, can all interact as participants. The "social network" is defined as a determinable structure of a finite set of actor who have social relations and communications with each other [14]. Electronic social networks like collaborative online technologies enable and encourage participation, conversation, openness, creation and socialization amongst a community of users. In such a network, people are connected through network either directly or indirectly. In the social network analysis literature, a tie establishes a link between a pair of actors [14; 15]. The ties and edges can define according to the business context based on friendship, work, or advice; and also depend on the content flows through actors like as resources, information, knowledge or affection with face-to-face or electronic method [16; 17]. Researchers have recognized that a broader sense of social network and network structure are a self-organized and decentralized construction of people, information, and communities of practices (COP). As it is hard to identify the borders of a network, one can refer to the unstable and unclear borders established by the network's participants. Using this viewpoint, shift the focus from identification and protection of a network borders to management and support of network relations.

The social network has been developed since the first decade of 21's century in the society. The purpose of public social media is to connect people through personal relationships such as friendship, interests or by other personal attributes and – through this – provide people with the means to interact in their circles, stay in touch, update each other, organize events and share content – all instantaneously, enabled by mobile devices people carry. Some of these properties are desirable in work contexts as well such as instantaneous information update, forming and maintaining relationships quickly and easily, and sharing content and knowledge.

The centrality of trust concept through the social interaction as an important mechanism for knowledge sharing clarifies the role of this concept on the knowledge management systems. Research about this issue is essential because on the one hand, investigation in the social network tradition has long established the importance of individual relations in the construction and gaining of knowledge [18; 19; 20]. Yet, on the other hand, there has been little research about what really happens when users trust to each other for work-related advice [19]. The scope of the work related information highlighted the social network which implement within organizational borders. The context of organization influences the knowledge sharing process and changes the volume of shared knowledge in the network. The knowledge management literature has identified a broad range of factors that can influence knowledge sharing. Trust is an important factor of knowledge sharing process. The trusting to employees is depend to node position in the social network. The present research was designed to help identify this positions.

3. Trust

Several definitions have been published for trust. Mayer and his colleagues defined trust as "*the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party*" [21]. This definition of trust is also demarcated for other side who is perceived to react with desire toward the trustor. Both sides define as knowledge recipients and the knowledge owner in the knowledge management area. Trust is a topic which is of ubiquitous importance factor in sharing knowledge. The willingness of employees to share and use knowledge depend on the level that co-workers are trusted recipients and knowledge sources [22; 23; 24]. Moreover, Structures of time, place, action and social relations in which people involve with sociotechnical systems, define the strength of people trust to the systems they are part of [25]. The lack of trust may be increased skeptical employees' behavior about sharing knowledge and thus, people try to hold their knowledge. Preparing a trustful environment between employees and group members support knowledge management system to facilitate knowledge sharing and dissemination process [26]. The complex network metrics evaluate trust by several network variables. The most important metric is centrality proportion. Community members attempt to receive information from sources who have several connections with others. It is a one approach to evaluate the quality of knowledge sources and trust to them. The most important metric for measuring the centrality is node degree. The impact of centrality for the trust relation is similar to the network density, dependently from in/out-degree when an individual has social interaction with neighbors [27]. The model that will be represented in the next part use the node degree for evaluating the trust at the enterprise social network. Moreover the model investigate relationship between knowledge sharing and date of creating nodes (joining to the giant component) as another criterion for measuring trust between knowledge recipients and knowledge possessors. These two rules represent the priority for knowledge recipients to gain knowledge in the organization.

4. Complex Social Network Models

Social relationships in terms of nodes and ties between humans could be used in various types of analysis. Social network metrics use for analyzing the structure of social networks. Understanding of social networks needs a complete and arduous description of a shape of social relationships as an essential starting point for analysis. The mathematical and graphic tools have been used for analyzing the social network structure.

For many social simulation models, the structure of the model is a first required step. The complex networks literature describes four basic forms of network structure: regular lattice, small-world, scale-free and random [28]. However, while these network structures precisely reflect some real networks, they do

not seem to be very good models of the enterprise social network. The enterprise social network affected by organizational behavior and the borders of the departments and communities.

Models created by random ties have been analyzed since the middle of the twentieth century, by Erdos and Renyi [29]. Yet the enterprise social networks are not random: for example, employees who work in the organization like to interact with others who are working in the same department. In 1998 Watts & Strogatz [30] research on the random re-wired graph which evolved from regular lattice. The graph structure represents a large clustering coefficient and small average shortest path length between nodes which they named a "*small-world*" network. Specifically, a small-world network is defined to be a graph where the typical distance L between two random nodes increases proportionally to the logarithm of the number of nodes N in the graph $L \sim Log\ N$ [30]. In 1999 Barabasi & Albert [31] introduced a "*scale-free"* network model evolved by *preferential attachment*, in which new nodes connect to those that already have many connections. The preferential attachment produces a graph with power-law degree distribution, thus the probability P(k) of a node in the network interrelates with k other nodes decrease by a power law $P(k) \sim k^{-\gamma}$ P(k). Since these power laws are free of any typical scale, such a network with a power law degree distribution is called a scale-free network model [31]. This issue specifies that large networks self-organize into a scale-free state, a feature unpredicted by all other random graph models [31]. Recently it has been researched about the preferential attachment as a key feature of social networks that distinguishes them from other network models [32]. The researches show the most part of the social network follow the scale free network model.

All network models show the specific type of model structure. Although none of the standard network models seem to be exactly fit for generating social networks for simulation, but the appropriate combination of the network models can be clarified with the restrictions of social real network.

5. Basic Structure of the Model

This paper presents an agent-based social network model for organizations and also investigates the relationship between trust and knowledge sharing through an enterprise social network. The main part of the model has come from Watts et al [33] research in which "*the probability of acquaintance between individuals*" "*decreases with decreasing similarity of the groups to which they belong*". Newman et al [34] mentioned that the model is "*possibly moderately realistic…based on a hierarchical division into groups*". Moreover, the organizational literatures emphasize the strong relationship exist between employees who work to gather in the same department or same project for sharing knowledge specially in the multinational corporation [35]. The physical environment makes a suitable area for employees to more interaction with each other and the same goal creates incentives for employees to share knowledge among team members. The project team members have a strong and frequent relationship with team members and also limited relationship with other employees around the organization [36].

The model represents two team project (department) within the firm. The limited number of departments can obviously show the result of knowledge sharing through enterprise social networks. The models were implemented using NetLogo agent-based model software version 5.0.1. The size of the networks restricted by organizational employees number. The model creates two clusters of 40 employees (80 nodes) in two departments. The model simulates social networks by generating preferential attachment with power-law degree distribution among the department's employees. The nodes generated parallel in two departments. It is important for evaluating the date of node's birth. Figure 1 illustrates the degree distribution histogram and Figure 2 shows the degree of the nodes.

Figure 1 and Figure 2 pinpoint to the facts that the department's network continuously develop by the addition of new nodes (employee) which are preferentially attached to existing nodes with large numbers of relations. Huge number of nodes (36 employees) have a one connection and few employees have more than 13 connections with other nodes. There are a few employees that have a very high centrality while the most of the others have very low degrees. Those nodes with low centrality proportion (belonging to the tail of the power law) are signified in peripheral positions in respect to central nodes and they added to the network recently. This simple behavior leads to power law degree tails with exponent $\gamma = 1.64922$. Moreover it also leads to low diameters with respect to the random graph [37].

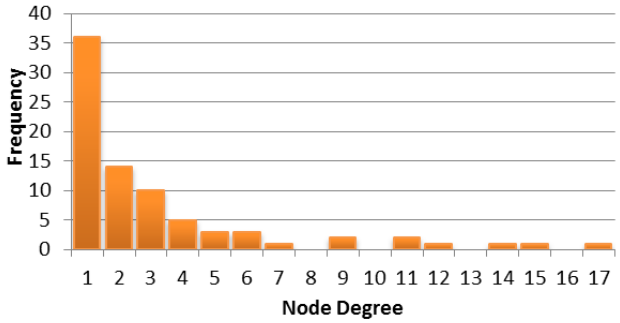

Figure 1- Degree distribution histogram

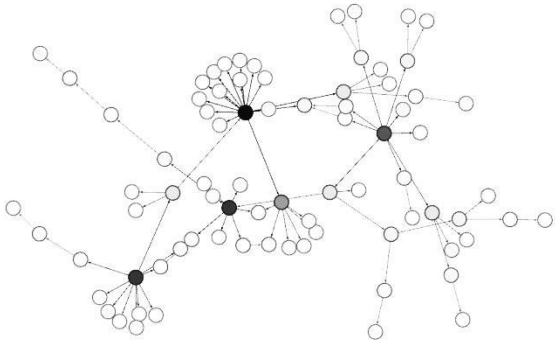

Figure 2- Lighter nodes have lower degree and darker nodes have higher degrees

In the next step of simulation, agent-based model makes connection between the departments. Department's networks have dependency between each other by random with low probability. There is a limit number of relationships between employees of two different departments or project teams. The relationship needs time and social interactions for maintaining the connection. This argument rests on the premise that it is

costly to maintain direct social relations to other organizational subunits [36]. The result of agent model shows around five connections between two departments by several simulations. The probability of making a connection between two nodes from different department is set by 12.5%. As shown in Figure 3, the internal graph generated by scale free method within the departments and makes connections between two departments by Erdos and Renyi network model. Also the graph density is 0.026 that represents departments and teams divided from each other by organizational structure. Although the enterprise social network attempt to close employees to each other and make a decentralized system for social interaction and knowledge sharing, but the organizational structure and organizational division create pressure on the enterprise social networks to makes low level of graph density in comparison with the other social network with same nodes.

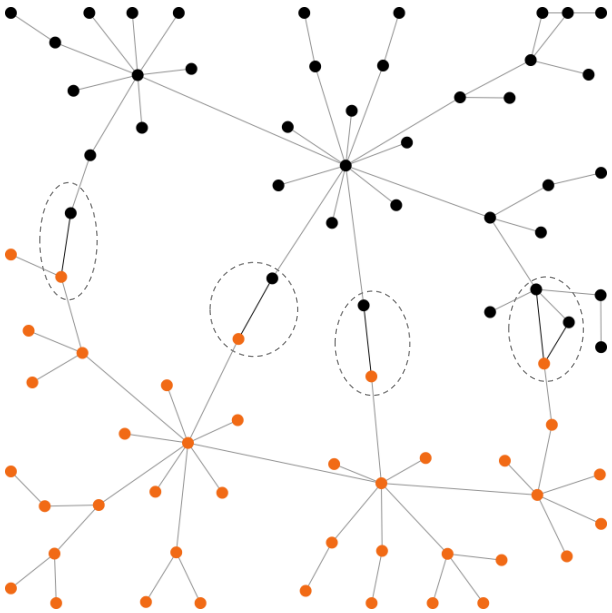

Figure 3- Two department (orange/black nodes) generated by the preferential attachment model, random connection created between departments

The average path length is 4.679 and the most of the nodes have no betweenness centrality because of peripheral position of nodes and a small number of nodes have high bitterness centrality. The betweenness centrality distribution is illustrated in Figure 4. The distribution verified the network which generated by agent-based model and also shows while random connection generated between departments, the preferential attachment network is a dominant structure for the enterprise social network.

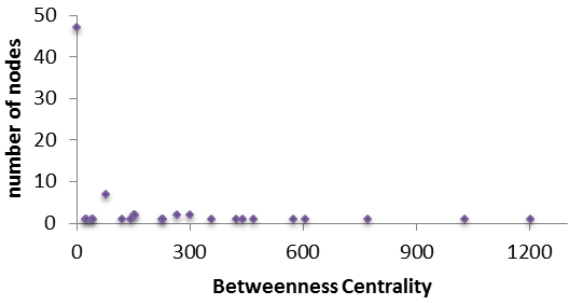

Figure 4- Betweennes centrality distribution

The next part represents knowledge sharing through the model. Although social interaction (social network) is essential for knowledge sharing, knowledge recipients also need to confide to the knowledge possessors. The individual direct trust to the knowledge sources in the enterprise social network is defined by the node degree. The node degree includes the number of connections within the department and with the other department employees. The agents make decisions about the selecting other agents to receive knowledge by calculating the degree of neighbors in the social network.

6. Knowledge Sharing through the Enterprise Social Network

The model simulates knowledge sharing between and within the two departments. All agents can receive and send knowledge to the other nodes. The model represents knowledge sharing by using pull system. Pull mechanisms are used by questions and answers, while push mechanisms are used for sending knowledge that is highly urgent for all employees in the organizational knowledge repository without any questions. The pull system increases the quality of knowledge by customizing knowledge objects according to the recipient's needs and also decrease the knowledge repository volume by sharing relevant knowledge. After generating the enterprise social network, the model selects 10 nodes randomly in each iteration for asking questions from other nodes. The main assumption is the node can find the answer through the social network. Knowledge recipients select the knowledge sources from their neighbors. The neighbor's answers prioritize by trust criterion (node degree). The node trust to receiving knowledge from nodes who have social connection and also have maximum social degree (prestige) within the enterprise social network. The quantity of knowledge for the whole network is fixed for each iteration. The total number of knowledge sharing normalized by the number of nodes and represent by τ . As mentioned in the social network part, the context of organizations affects the knowledge sharing behaviors. The circumstances of organizational context permit the average time of sharing a specific quantity of knowledge (number of knowledge object being shared) to vary. The model use several τ for measuring knowledge sharing in the organization.

$$\tau = \frac{Number\ of\ knowledge\ being\ shared}{Number\ of\ nodes}$$

The model elucidates the role of hubs as critical positions in the enterprise social network for knowledge sharing. Figure 5 represents the frequency of knowledge sharing by nodes and Figure 6 represents the relationship between the nodes degrees and sharing knowledge for sharing 500 knowledge. a node with

a high degree has a high chance to be involved knowledge sharing. The diagram shows that the node's degree has a strong relationship with the quantity of sharing knowledge. The quantity of knowledge which being shared rises with increasing node's degree. Few nodes represents as a critical positions for sharing knowledge through the enterprise social network. The histogram shows that 71% of knowledge transferred by only 9.25% of employees. These nodes have critical position on the enterprise social network structure. These employees (nodes) illustrates by region on the Figure 6 who have high degree in the network structure. Organizations attempt to keep these people by human resource strategies and make incentives for them to sharing more knowledge.

On the other hand the trend line regression of point plot at Figure 6 shows that the speed of increasing knowledge sharing reduces at the right side of the plot. It shows a threshold that the slope will be zero and the increasing degree couldn't change the quantity of individual sharing knowledge. It shows that the quantity of knowledge sharing doesn't have a relationship only with the number of social connections, also the knowledge sharing depend on the other resources (like time) that knowledge owners spend for sharing knowledge. Thus any nodes share a limit number of knowledge through social connections because of the knowledge sharing costs. The data show 9.822 of knowledge objects as the maximum individual threshold of knowledge sharing for the knowledge sources.

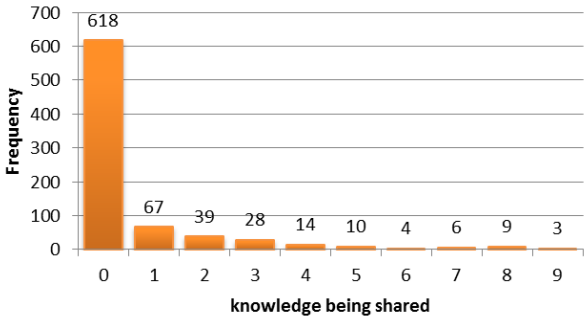

Figure 5- Knowledge sharing degree histogram

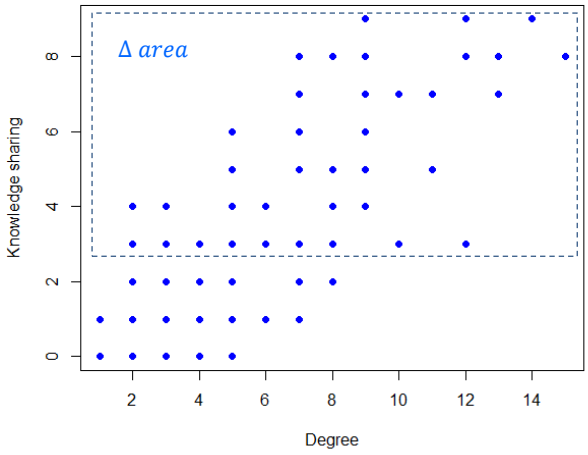

Figure 6- Degree and knowledge sharing

The simulation repeated by several τ . As can be seen from Table 1, the thresholds are calculated. Figure 7 represents the relationship between number of knowledge sharing and the node degree from different volume of knowledge sharing in each iteration. The curves show the number of knowledge being shared by knowledge sources. The curves explain the threshold of knowledge sharing as a maximum quantity of knowledge sharing for each node. As mentioned in the previous paragraph, although, the knowledge sharing increases because of increasing knowledge sharing but the knowledge owners have limited ability and resources for sharing knowledge.

Table 1- node's knowledge sharing thresholds

Number of knowledge sharing in the network	τ	*Individual knowledge sharing threshold*
16	0.2	8.4044
24	0.3	15.0111
32	0.4	25.8988
40	0.5	46.5783

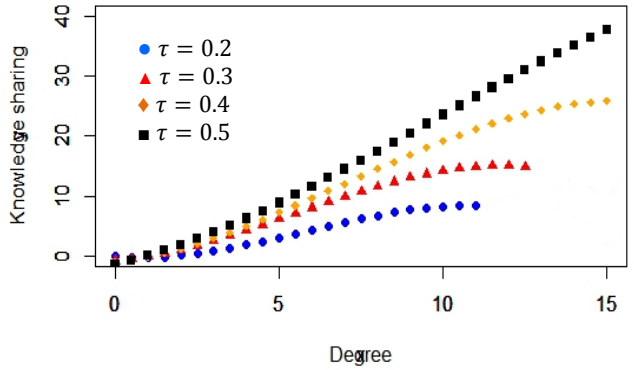

Figure 7- Trend lines of knowledge sharing

7. Employees Experiences and Knowledge Sharing

section 6 represented the importance of the hubs in the social network. This part signifies experiences of employees as another important factor of knowledge sources in the network structure. The model defined experiences of employee as a time that employee is recruited to the organization and join to the organizational network. The model calculated how long a node has been joined to the giant component.

The agent based model calculates the date of node generated when a node added to the social networks. The results indicate employees trust to the other employees who have a large presence in the organization because of the their experiences and their backgrounds. The model assesses the relationship between the generation date of nodes and knowledge sending to the other nodes through the network. The results emphasize the role of knowledge workers through the organizations. Knowledge workers are staffs who have a deep background in education and experience. These people have strong experiences and valuable

tacit knowledge and need suitable structure for sharing knowledge. The social networks help these people to share knowledge with other employees and use their experiences for improving the organizational performance. Furthermore, the result shows that knowledge recipients trust to the knowledge worker and their knowledge quality because of the their prestige and their experiences on the social network. Their prestige represents the history of presence in the organization and also their connection with other knowledge sources. As shown in Figure 8 and Figure 9 illustrate dates of joining to the network and nodes degree and also knowledge sharing through the social network. Both plots show the strong relationship between date of node generation and these two variables.

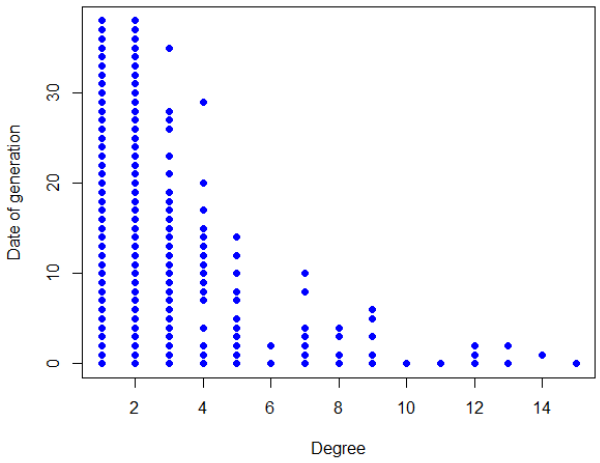

Figure 8- Date of generation nodes and nodes degree

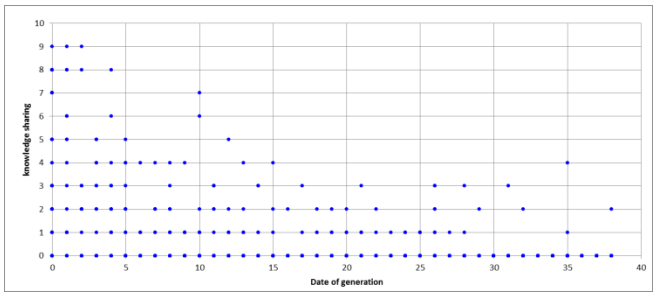

Figure 9- Date of generation and knowledge sharing

Moreover, the results show that hubs have a big background and joined earlier to the network. It shows the trusting to the knowledge sources in not relevant only to the past experiences, also knowledge sources should be present on the network and communicate with the other nodes and make social connections with other nodes.

8. Conclusion

Due to developing social networks and the need for faster and effective communication, currently a lot of enterprises moved to using social network technologies as one of their main communication tools within the organization. The paper presents an agent-based model which attempts to explain sharing knowledge through the enterprise social network. Several models have been presented in the literature of social network and our model focused on the two main exploited network models, 1) Erdos-Renyi random graphs, ii) Barabasi-Albert preferential attachment in the organizational environment.

The model generates a network by preferential attachment within departments and random graph between departments. This model represents the real social network among employees which people like to make social connections with other people who have large connections with others. The enterprise social network is used for knowledge sharing in the organization. Trust is an important issue for sharing knowledge through the enterprise social network. Our model investigating in respect to the recipient's trusting. The knowledge recipients trust to the knowledge sources who acting as a hub in the enterprise social network. The agent-based model emphasizes the role of hubs as knowledge sources and knowledge brokers in the organizational social graph. The employees trust hubs because of their connections and their record on the social networks. Trusting is not depend only to the agent experiences, it depend on their activity on the social network and observed by other nodes. Removing hubs from enterprise social network can vulnerable interdependent networks within departments and between departments.

Knowledge sharing threshold calculated for employees. Although the sharing knowledge depends on the number of connections, the threshold of knowledge senders shows that the maximum quantity of knowledge that send by an employee through the enterprise social network. The paper shows the different individual knowledge sharing threshold for different quantity of knowledge sharing of the network.

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