The Network Diameter and Its Impact on Company Performance

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Abstract--**This study shows how the impact of network evolution on the network's overall performance is mediated by the network's diameter. Our principle argument in this paper is that the diameter serves as a criterion to measure the performance of a network structure. A small or reduced diameter indicates tight relationships between the vertices comprising the network. This facilitates higher network capacity and flow between the vertices, which, in turn, leads to better overall performance of the network. On the other hand, a larger diameter leads to performance degradation due to a loosely connected network.**

I. INTRODUCTION

This paper studies the evolution of business networks. A business network is a kind of social network whose entities are organizations or companies and its relationships are the business activities between those organizations [22]**.** Those business relationships serve as elements of a network structure. We examine how the evolution of a business network affects its performance by investigating a key measurement of any social network – its diameter. The diameter is defined as the maximum distance between all pairs of vertices [36]. The distance between two vertices is defined as the length of the shortest path between them, assuming there is such a path. A path between two vertices exists if and only if both vertices are linked together, either directly or indirectly through other vertices. The length of the path is the number of edges it has. Thus, the diameter represents the largest nodal eccentricity and is a network characteristic that evolves as the links between network vertices change.

Our contention in this paper is that the evolution and performance of business networks can be more fully understood by examining their diameter. One way to deepen understanding from this vantage is to investigate the evolution of business networks over time. A popular approach in this context is to examine real world networks. For example, [25] explored two online social networks; [28] studied patterns in citation graphs; [18] studied network activities of entrepreneurs through three phases of establishing a firm; [14] explored patterns of network development in information technology start-ups. Nonetheless, studying real world business networks, external factors like economic changes may overwhelm other factors in determining network structure, growth and as a result – its overall performance.

Another way to examine networks and performance is to investigate this domain using a simulation. Simulations are considered important motivational and learning tools [16], a link between abstract concepts and real-world problems, a "learning by doing" or "hands-on" approach ([24], [29]). We use a simulation as the means by which to establish a realistic environment for laboratory research on business networks and as the means by which to foster a heightened awareness of network attributes in order to gain insights regarding organizations conduct and performance.

Our investigation begins with a section reviewing network literature and simulations. Then, we introduce the study's hypotheses and present the study's methodology. Next, we discuss the value of using a network approach in a simulation design, followed by an analysis of performance, according to the network diameter. Finally, we discuss the applicability of this study and propose some future research directions.

II. LITERATURE REVIEW

A. Network Theory

Increasing interest in networks research in recent years has resulted in an exponential growth of studies across several disciplines in this area (see [6] for a comprehensive literature review). Network theory is an interdisciplinary field that searches for a common formalism for networks found in real-life. The goal of network theory research is to gain a greater understanding of the structure and flow patterns within networks.

Networks exist in all aspects of life (see [31] and references therein). Some illustrations are as follows: (a) social networks are sets of people with interaction patterns between them; (b) citation networks and the World Wide Web (WWW) are examples of information networks; (c) technological networks are man-made networks designed typically for the distribution of commodities or resources, such as the electrical power grid and the Internet; and (d) biological networks, where substrates and products are connected with metabolic processes between them.

Each network consists of basic atomic units, called *vertices* (e.g., people, web pages, power plants or substrates) and means by which they are connected, called *edges* (e.g., relationships, hyperlinks, power lines or metabolic processes).

In this study we focus on the practical aspect of networks and measure their influence on entity performance. In general, networks can operate on different levels and the relationships between the actors play an important role in how problems are modeled and solved. An extensive literature review of networks research (and its application in a social context) may be found in [8], [15], [23], [34], [36] and [39]. There is also a growing body of research that is coming to terms with the economic consequences of organizations participating in social or strategic networks (e.g., [19], [20]). This underlines the importance of understanding network theory, and highlights the need for focusing research on this area. We address this notion using the platform offered by simulations.

B. Simulations

A simulation is, by definition, a highly complex man-made environment. A simulation offers participants the opportunity to learn by doing in as authentic a management situation as possible and to engage them in a simulated experience of the real world (e.g., [4], [16], [29]). This approach to simulation design enhances its characteristics to mirror real-life and the observed participant behavior may be generalized to reality [26].

Over the years, researchers have reported the extent of usage of simulations in both academe and business (e.g., [1], [2], [9], [10], [11], [13], [35]). The Information Systems literature also suggests the application of simulations as a learning tool. For example, [32] suggested a system development simulation in which failure and escalation are introduced to Information System students; researchers, such as [12] and [27], used a simulation game to teach Enterprise Resource Planning concepts; [33] explored an Internet-mediated setting to simulate an electronic commerce environment; [3] used a simulation to teach decision technology and decision support systems.

Overall, the simulation method enables participants to "learn by doing" [16]. A simulation provides participants the opportunity to take on the roles and responsibilities of executives, to become deeply involved in decisions faced by real people in real organizations, to feel the pressure and to recognize and to assume the risks. Moreover, this method is an excellent tool to test the understanding of theory, to connect theory with application, and to develop theoretical insights in a laboratory environment. The participants are provided the opportunity to develop some useful practical skills and to practice the tools, techniques and theories they have previously acquired.

III. HYPOTHESES

In this study, we focus on the practical aspect of networks and examine how collaboration between organizations impacts their performance. We also examine the role the diameter plays in network performance. Numerous studies examined the structure of networks and the characteristics of their vertices from different perspectives (e.g., [6], [8], [31]); however, the way through which network characteristics affect performance is still largely unknown.

Studies investigating the economic consequences of social or strategic networks show that organizations enter alliances to improve their competitive position (e.g., [7], [17], [20]). It seems clear that better strategies for disseminating information and diffusing innovations through communities using social influence processes need to be devised [37]. In this study we examine how networks can profit from company or organizational collaboration. Therefore, we hypothesize:

Hypothesis H1: Organizations collaborating with other organizations outperform organizations that do not.

In addition, we strive to explore how entities may achieve a competitive edge by concentrating on a certain network characteristic – the network diameter. We argue that the structure of a network and its diameter characteristic are vital to forecast the network's overall performance. Nevertheless, the way through which the diameter affects performance is still understudied. In this study we investigate the above phenomenon.

Beyond representing the longest path (or connectivity) between any pair of vertices, the diameter concomitantly serves as a criterion to measure the performance of a network structure [5]. A small or reduced diameter indicates tight relationships between the vertices comprising the network. This facilitates higher network capacity and flow between the vertices, which, in turn, leads to better overall performance of the network (see, for example, [21]; [38]). On the other hand, a larger diameter leads to performance degradation due to a loosely connected network [30]. Therefore, we hypothesize:

Hypothesis H2: The network diameter negatively impacts network performance.

IV. METHODOLOGY

A. The Simulation Employed

In order to gain significant insights from applying network theory using a simulation, the simulation must fulfill three fundamental requirements: First, it must hold numerous basic atomic units, or vertices, that interact between themselves. Second, this interaction should be properly defined and measurable. Third, each vertex must have a properly defined performance measure.

We used a simulation developed in the United States, commonly known as the International Operations Simulation - INTOPIA B2B (http://www.intopiainc.com), hereafter INTOPIA. The simulation is designed to yield substantial payoffs in practical training. It involves the participants in the executive process, motivates their need for decision-making aids and forces them to adopt a managerial viewpoint.

The simulation is highly realistic, meant to simulate the total environment. Participants immerse themselves in an artificially created industry. Incoming participants, working in groups ('organization') take part in six or more simulated periods. The task of the organizations is to make decisions which will guide operations (simulated by a relatively easy computer interface) in the current period and which will affect operations in subsequent periods.

Decisions were made once a week and were e-mailed to the simulation administrator to be fed to the computer program. After the program ran the data, it generated outputs that included financial reports (e.g., a balance sheet, an income statement) and market reports. These outputs were then e-mailed to the groups and were used for their decision making in sequential periods. Dozens of decisions, covering the entire range of a typical enterprise, were required of the groups in each simulated period. Each group (organization) assumed one (or more) of the following organizational roles: innovative research and development (R&D) organization, developing different patents, manufacturer, distributor or wholesaler. The decision-making process was based on an analysis of the organization's history as presented to the participants at the beginning of the simulation, interaction with other organizations and the constraints stated in the simulation manual. The performance of an organization in each period was affected by its past decisions and performance, the current decisions, simulated customer behavior, and the competition – the other organizations in the industry.

B. Participants and Procedures

This study was conducted in a university accredited by the Association to Advance Collegiate Schools of Business (AACSB). The participants were senior MBA candidates. We conducted five (independent) runs of the simulation, each with different participants. Table 1 details the number of simulated organizations created in each run.

At the beginning of each run, the students were asked to form competing teams. The formation of the teams and allocation of executive roles within teams proceeded without any external intervention or manipulation, and were reported to the instructors before the simulation itself began. Our experience shows that executive roles are usually allocated according to the participants' expertise in certain functional areas (e.g., accountants and bankers are usually assigned the role of chief financial officers). In each run, we recorded the decisions made by all the teams. We also kept track of the teams' performance. For this research, we aggregated all the results and statistically analyzed them, as presented later.

V. RESULTS

A. Network Analysis

This study proposes analyzing the INTOPIA simulation as a network, with all of the associated implications being acknowledged. In Table 1 we detail the number of organizations the students operated in each run. As can be observed, the number of entities in the industry varied from 16 to 20 organizations, with an average of 17 organizations.

TABLE 1. THE NUMBER OF ORGANIZATIONS IN EACH RUN.

Semester	Run I	Run II	Run III	Run IV	Run V
No. of Organizations	20	17	16	16	16

We consider INTOPIA as another kind of an information network, where each organization serves as a vertex and its relations or interactions with other organizations (licensing, inter-organizational sales, etc.) are considered as edges. Figure 1 illustrates the network structure at the end of Run I. The industry was made of 20 organizations. Figure 1 demonstrates the complexity of the network structure in the simulation. Note that in that particular example, 19 organizations had a least one collaborator (entity 11, for example, had 5 collaborators). One organization, entity 18, did not collaborate with any other organization.

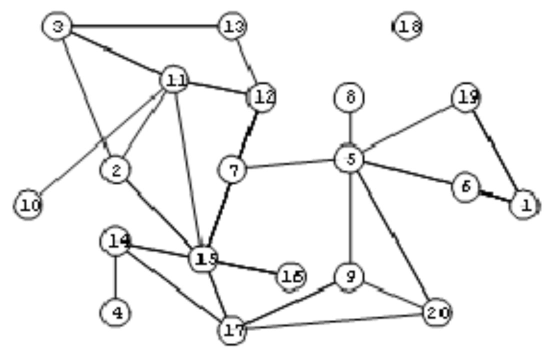

Figure 1. Network structure at the end of Run I. The industry consists of 20 organizations and exhibits a complex network structure.

Table 2 presents the average number of edges of each organization in each run and the standard deviation. On average, in all five runs, each organization had 2.51 edges on average with a standard deviation of 1.39. The correlation between the number of organizations and the number of edges is 0.48, indicating that the larger the number of organizations participating in the simulation, the larger the number of interactions between them.

TABLE 2. THE NUMBER OF EDGES PER ORGANIZATION IN EACH SEMESTER.

Semester	Run I	Run II	Run III	Run IV	Run V
No. of Organizations	20	17	16	16	16
No. of Edges per Organization	2.70	2.59	2.56	2.63	2.06
Standard Deviation	1.63	1.42	1.31	1.36	1.24

B. Investigating the Hypotheses – Performance and Diameter Analysis

This section examines the research hypotheses and tests entity performance versus network characteristics. In all runs, entity performance was measured by its accumulated retained earnings (i.e., the accumulated profits). For example, Table 3 exhibits the performance of organizations in Run IV in absolute values and in percentage, relative to the average organization in that run. The average organization in Run IV achieved accumulated retained earnings of about 3.1 million dollars. Entity 6, for example, achieved accumulated retained earnings of more than 10 million dollars, which is 238% more than the average organization in that run. Note that organizations that achieved negative profits may present performance worse than -100%. To avoid biases, we do not measure entity performance in absolute values, but in percentage, relative to the average organization of the

TABLE 3. PERFORMANCE IN ABSOLUTE VALUES AND IN PERCENTAGE RELATIVE TO THE AVERAGE ORGANIZATION IN RUN IV

Entity No.	Performance in Absolute Values (in K$)	Performance (in %) Relative to the Average Organization
1	1,267	-59
2	(456)	-115
3	1,358	-57
4	6,248	100
5	(2,354)	-175
6	10,564	238
7	562	-82
8	(3,214)	-203
9	1,267	-59
10	16,234	419
11	(235)	-108
12	23	-99
13	(5,248)	-268
14	3,624	16
15	7,562	142
16	12,834	310
Average	3,127	0

TABLE 4. ENTITY PERFORMANCE – HYPOTHESIS H1.

Run	Run I	Run II	Run III	Run IV	Run V
% of collaborating organizations	95	88	94	94	87
Performance of single organizations	-42.68	-8.98	-31.68	-59.00	-20.54
Performance of collaborating organizations	2.24	1.20	2.11	3.93	2.93

TABLE 5. RESULTS FOR THE IMPACT OF THE DIAMETER ON PERFORMANCE - HYPOTHESIS H2

Variable	Coefficient	t-stat	p-value
Intercept	24,436	7.05	<0.001
Diameter Size	-1716	-2.10	0.049

associated run. For example, the performance of entity 6, described above, would be 238 (which represents 238% more than the average organization), while the performance of entity 9 would be -59. We emphasize that the results in this section are aggregated for all five runs.

In all runs, 85% or more of all organizations collaborated with at least one other entity. Table 4 shows the average performance of the collaborating organizations and the 'independent' organizations (those organizations that decided not to collaborate) in each run, relative to the average organization.

The results reveal that organizations that did not participate in alliances with other organizations had below-average results. We cannot determine that all results are significant due to the relatively small number of organizations. We also note that some of the collaborating organizations performed much worse than the 'independent' organizations in the same run, but overall, on average, collaboration prevailed and thus, Hypothesis H1 is supported.

An investigation of the relationship between the diameter and network performance reveals a negative correlation of -0.23. A more though analysis using a linear regression reveals that a small or reduced diameter, signifying tight relationships between the network's vertices, easing network flow, leads to better overall performance. On the other hand, a larger diameter, which indicates a loosely connected network, leads to performance degradation. The regression results are presented in Table 5. The results are statistically significant and support Hypothesis H2.

VI. DISCUSSION AND CONCLUSIONS

This research used network theory concepts to better understand how organizations should position themselves within the network they are embedded in. For that, simulated organizations were formed. Although the general environment was mutual to all participants, the organizations became differentiated: each assumed considerably a different strategy, different operating decisions, and a different approach to collaboration with other organizations. Leaving the decision on network strategy to the groups resulted in a variety of behaviors toward other organizations in the industry: fully integrated organizations that conducted all the activities along the supply chain themselves, wholesalers that developed dependency in other entities, innovating organizations that sold their R&D products, etc. It appears that these organizations reflect most real-life approaches in industry.

Beyond the creation of simulated organizations and industries, this study tested two hypotheses relating structure, a network characteristic and entity performance. Both hypotheses were confirmed. These results agree with those of previous similar field studies (e.g., [17], [40]). As it turns out, the relationship between network evolution and network performance is mediated by another network characteristic – the network diameter.

Nevertheless, although simulations today present sufficient complexity to provide realistic network features and characteristics, no simulation can seize all aspects of real-life networks. As more data from real networks become available, it will be easier to determine the extent to which simulation situations resemble reality. Therefore, the applicability of the simulation findings to the real-world must be examined with caution. Also, there is a need to determine how simulations can be applied in studying various aspects of networks. For example, in real-life markets, new companies are constantly formed. This contrasts the experimental environment to the extent that all companies formed simultaneously. In addition, this study was conducted with students, which is a limitation by itself, as students do not necessarily present the characteristics of real company executives.

In future research, we wish to look more closely at the way networks are formed. A deeper investigation may provide important insights to better comprehend these collaboration relationships and address the notion that some organizations succeed in coalescing into collaborative components while others suffer from conflict.

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