Organizations analysis with complex network theory

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Abstract. In this paper, we propose network measures and analytical procedures for modeling the structure and the behavior of the basic types of organizations, such as: line, functional, line-and-staff, project and matrix organization. In order to obtain some tangible information about the connectivity between employees and structural properties of organizations, we develop network generators for all five types of organizations. We review various roles and groups of employees within the organizational network, and we assess social position and impact of a particular employee. Except, assessed locations of actors within an organizational network, we analyze the structure of network to find specific employees who have similar roles in the organization and have a tendency to be equivalent in terms of their potential to act in the organization. We estimate what is the confidentiality of the organizational network depending on the removal of a certain communication between employees and what is the percentage of communications that disconnect the organization in unconnected parts.

Keywords: Organization**,** complex networks, organizational network models, measurements, organizational network analysis.

1 Introduction

Management is a multidisciplinary activity that plays a crucial role for development of organizations. It is characterized by universality, but its implementation requires respect on the particularities for each organizational type, separately. In fact, globalization as a social phenomenon imposes new standards in management of organizations. In that way, connections and flows between employees in organizations are often unplanned and unpredictable. Also, organization's growth must be sporadic and self organizing [1]. Therefore, the main goal of this work is to analyze the basic types of organizations using the concepts of complex systems. Complex systems are an inevitable part of infrastructure of the modern world, and they can be represented as networks with a certain number of nodes joined together by edges [2,3,4]. People with its functioning establish mutual links and create social networks for exchanging information, views and ideas. As an example of such networks can be listed networks of friends, networks of people with specific training and organizational networks [5]. Organizational networks [5] play a key role in hiring, business success, and in job performance [6]. Nodes in organizational

networks (which are generally individuals of organizations) are tied by one or more specific types of interdependency, such as values, visions, ideas, financial exchange, friendship, kinship, dislike, conflict or trade. Network communications between employees are unevenly distributed, so some areas of organizational network have high density of links, while other areas are poorly connected. Thus, organizational networks correspond to small-world networks of Watts and Strogatz [7,8,9,10]. The main goal of this work is to analyze basic types of organizations and evaluate functionality and location of employees using the model [11,12] developed by David Krackhardt. Similarly, individuals can exercise influence or act as brokers within their organizations by bridging two parts of organizations that are not directly linked (called filling structural holes) [13]. Thus, discovering mapping of relationships and flows between employees and also exploring the structure of organizations or nodes that are most suitable to achieve the desired goals of organizations is of great importance for every organization. This analysis provides ways for companies to gather information, deter competition, collude in setting prices or policies and pick up which type of organizational structure is most suitable for the company.

The rest of the paper is organized as follows. In Section 2 we present a short overview for basic types of organizations, line, functional, line-and-staff, project and matrix organization. Afterwards, in Section 3 we give a description of the various network metrics for modeling organizations, and we give simulation results and analysis. Section 4 concludes this paper.

2 Types of organizational structures

Organizations can be structured in many different ways and styles, depending on their objectives and ambience. Structure of an organization determines modes in which it operates and performs. The most common types of organizational structures are: line, functional, line-and-staff, project and matrix organizational structure [14].

2.1 Line organizational structure - LO

Line organizational structure is the oldest and simplest type of organization. It is characterized by direct transfer of authority from top, through various managers to workers and following the command chain tends to simplify and clarify the responsibility and authority in the organization. This organization has no positions of staff or advisers, so is less expensive in terms of costs. In addition, simplicity and comprehensiveness make a clear separation of authority and accountability among managers, easier, faster and more stable decisions. Line organizational structure promotes fast decision making, which enables faster change of direction, because several people will be consulted on issues as they arise. Also, there is greater feeling of closeness between managers and employees. This structure may depend on few key people who carried out a number of things and furthermore may appear insufficient efficiency if the organization grows.

2.2 Functional organizational structure - FO

Functional organizational structure was introduced by Frederick W. Taylor, who was trying to establish specialization in management. In functional structure people are grouped according to their ability to perform similar tasks, such as: marketing, manufacturing, finance, personnel, investment, research and development. Functional

authority has direct line authority of a special function or activity. Main advantages of functional structure are: efficient utilization of resources, technical high-level solving problems and clear opportunities for promotion within the function. Each function is operated by a specialist and an assembly of experts is always available to employees. Finally, functional organization overcomes the lack of line organization, which is inefficient control of one employee. However, high degree of specialization, involve series of specialists who operate not as a system, but as independent entities. As a result, organization often has a lack of good governance.

2.3 Line-and-staff organizational structure - LSO

Line-and-staff structure is developed to take advantages of line and functional organizational structures. In fact, line part of the line-and-staff organizational structure is used for emphasis on stability and discipline, while staff part serves to bring expert knowledge for solving problems. However, authority and responsibility of staff may cause confusion if is not clearly set. Introducing of staff personnel may cause line managers to feel that have lost authority over a particular specialized function or that depend from staff, so they lose the ability for original thoughts, initiatives and actions [15].

2.4 Project organizational structure - PO

Project organizational structure provides high efficiency. It is a temporary organization established to achieve concrete results by using a team of specialists from different functional areas within the organization. Team is focused on the project. When the project is completed, project team is disbanded and its members are returning to their regular positions in the organization. Project organizational structure is possible when the job is [16]: defined in specific goals, tasks and terms to complete; unique and unusual for an existing organization; complex, respecting the interdependence of activities and specialized skills necessary to achieve; critical in terms of income or loss, and temporary, with respect to the duration of needs.

2.5 Matrix organizational structure - MO

Concept of matrix organization gets in importance in recent decades and represents an extension of concept of project organization. Matrix organization is based on application of two types of organizations, functional and project way of departmentalization. It is also called dual or hybrid organization. Matrix organizational structure does not apply in all companies. It is a complex structure and its application must meet certain conditions. This structure has a high degree of flexibility in utilization of human resources, rapid adaptation to changes, strong manufacturing and project coordination. Furthermore, it enhances and develops skills, increases motivation and commitment and assists in planning in top management [17]. Besides this, matrix organization manifested certain weaknesses, such as: violation of principle of unity of command, creates confusion with double authority, requires time and generates high costs for execution because requires a high level of interpersonal interaction.

3 Simulation and Results

In this section, we give a short description of the various network metrics for modeling organizations, and we interpret them in the context of organizational network analysis using the measured results. For our simulations, we are using a network generator. The generator generates samples of the 5 various types of organizations, preserving their basic characteristics. Each sample has a different number of nodes (N) ranging from 35 to 1900 employees. In Figure 1 is given a simple toy organization with 35 employees in order to illustrate the structure of the line organization.

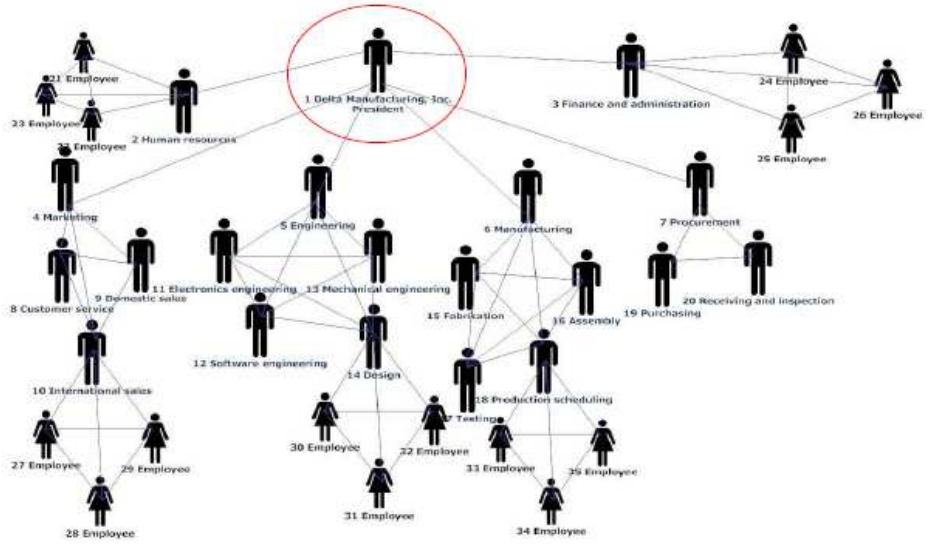

Fig. 1. Line organization with departments for Human resources, Finance and administration, Marketing, Engineering, Manufacturing and Procurement. Delta Manufacturing, Inc. President (in the red circle) is the top manager of this toy organization.

3.1 Structural equivalence

First network metric that can be applied in a social context is a clique. The clique consists of people who mutually communicate with one another. The clique within organizations can be based on attributes that are present within employees in organization [18, 19, 20], e.g. race, age, mobility, educational achievements and location. Thus, employees who belong to same clique have similar job responsibilities and as a consequence those employees should be physically close or in same offices.

Through analysis of structural equivalence, we revealed social position or set of employees with similar ties to others. Analysis uses Euclidian distance for structural equivalence. Euclidean distance between nodes i and j is calculated by their vectors of links to and from the other *N-2* employees in the network, excluding loops and common links:

$$d_{ij} = \sqrt{\sum_{k=1}^{N-2}\left[(x_{ik} - x_{jk})^2 + (x_{ki} - x_{kj})^2\right]}, (k \neq i \neq j) \quad \textbf{(1)}$$

Figure 2 presents dendrogram for hierarchical clustering using the concept of structural equivalence for the toy organization in Figure 1. This line organization has

9 clusters of employees, which are similar in their social relations. Employees with ordinal number 33, 34 and 35 belong to same cluster and are structurally equivalent, so if any of them is absent from work for a longer period or there is another work with higher priority, manager can find his replacement from the same because everyone of that cluster has same connections to other employees in the organization.

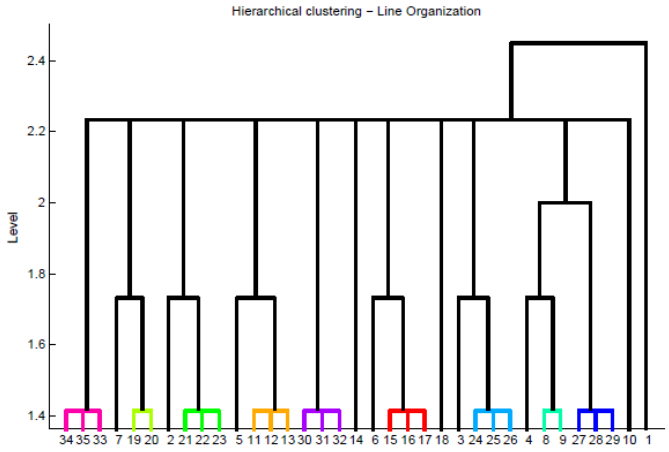

Fig. 2. Hierarchical clustering for line organization with 9 clusters of employees that have the same position in the organization with similar relationships to others and same potential to act in the organization.

3.2 Average path lengths for organizations

A small average path length for organizational network indicates that anyone can reach someone else simply and quickly, without going through intermediate colleagues. In other words, shorter paths mean a faster arrival of information, which is less distorted and employees have better visibility and awareness of what is happening in other parts of organization. Mainly, shorter paths are important for better learning within the group and for effective reconfiguration after topological changes. From the analysis shown in Figure 3 (left), the functional organization has the larger average path length. This is consequence from the fact that employees from one functional department do not communicate with employees in another department, because they are appointed for a single specialized function. In functional organization the main lack is communication between functional managers and between employees who are specialized for different functions within the same or different department. To be more precise, the average path length is around 5 form small organizations (with no more than 100 employees), then it starts to increase and for bigger organizations (with 1500 employees) it is around 7. In the case of project organization the average path length is smaller than that for functional organization because there is communication within a given project (Figure 3, left). In the case of the average path length from the top manager to the rest of the employees the results differ, i.e., both, the functional and the project organization have the same value (see Figure 3, right). This result coincides with the real work of project organization, because project organization is the highest form of organization with a very small span of management, with mostly hierarchical levels, more channels of communication and difficult coordination.

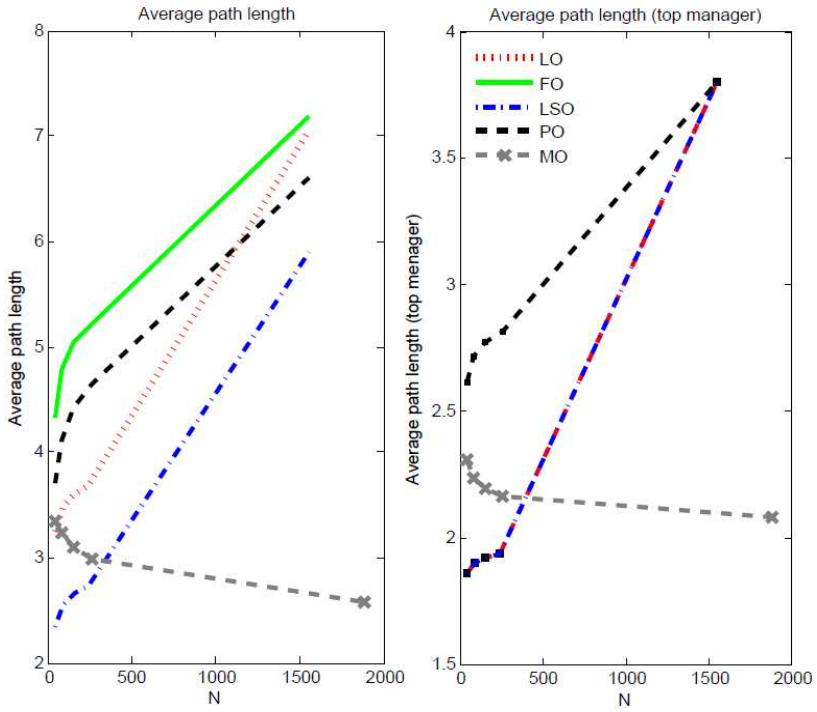

Fig. 3. Average path length for entire network (left) and from the top manager (right) for growing line, functional, line-and-staff, project and matrix organizations.

From the analysis made, (shown in Figure 3) we can conclude that the line organization is good for small number employees (up to 50). In the line organization, employees that are in given department communicate with each other because they are not specialized for a particular job and must exchange information, knowledge, and often change their positions within the department in order to accomplish their tasks. The average path length for the line organization has the steepest growth, making it not suitable for lager organizations.

Results of Figure 3 shows that line-and-staff organization has better results than functional, line and the project organization. This is because line-and-staff organization belongs to flat organization where there are less hierarchical levels, immediate communication, easier and more efficient coordination. Finally, the matrix organization is a winner-winner for large organizations, because the average path length of the whole network (Figure 3, left) and the average path length from the top manager (Figure 3, right) decreases by increasing the number of employees. The result for lowest average path length for the average path length from the top manager in larger organizations, with more than 1000 employees, confirms the fact that this type of organization helps in planning for top management and has more time for long-term planning, given the fact that the matrix structure allows daily operational decisions to be delegated to the project and functional managers. In our simulations, the average path length for matrix organization with 1500 employees is more than 2.5 times smaller than the other types of organization. The average path length from the top manager is around 1.5 times smaller.

3.3 Labeled average path lengths for organizations

Figure 4 presents average path lengths between managers and employees in all types of organizations. Within this research we label every node of network as employee or manager. According to results for average path length between managers and employees of all organizations in Figure 4 and characteristics of different types of organizations in Section 2, it can be seen that these basic characteristics of each organization are confirmed and they meet similar form as in Figure 3. For organizations with 250 employees, the biggest average path length has the functional organization, around 3.4, the project organization has around 3, the line organization has around 2.7, the line-and-staff organization has around 2.6 and the lowest average path length has the matrix organization, around 2.5. It is obvious that the average path length will increase as new employees are employed in the organization for all type of organizations, except for the matrix organization.

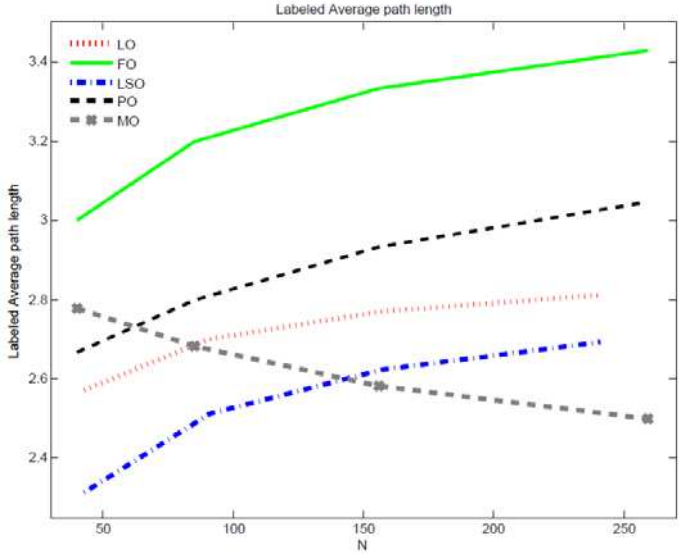

Fig. 4. Labeled average path length between managers and employees for entire network, for growing line, functional, line-and-staff, project and matrix organizations.

3.4 Hierarchy for organizations

Hierarchy answers questions like: how to find nodes constituting the highest part of the hierarchical structure of network or how to measure strength of the hierarchical structure. We measure strength of hierarchy as defined in [21]. Functional organization has biggest hierarchy (Figure 5), which coincides with definition of this type of organization because functional managers are specialists in those areas that work, and the line of authority is functional or diagonal, meaning that functional manager has precise authority over the functions carried out. Then follow project and line organization, and the remaining two organizations have lowest value for hierarchy, because they introduce additional personnel and management staff who can communicate with employees and weak hierarchy. It is important to note that increasing the number of employees in line and line-and-staff organization introduces new hierarchical levels and these two organizations are more hierarchical compared with project organization. Matrix organization with a larger number of employees is at least hierarchical, which is consistent with its definition.

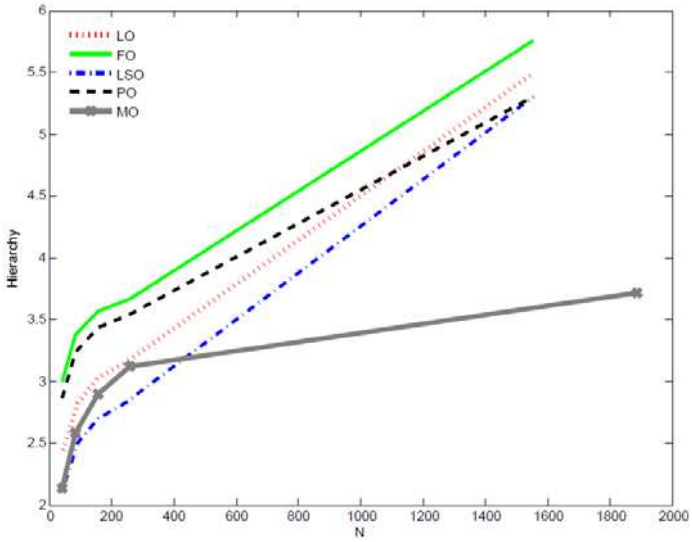

Fig. 5. Strength of hierarchy for growing line, functional, line-and-staff, project and matrix organizations.

3.5 Redundant paths

Path redundancy is a key measure for organizations when employee leaves organization or is absent for a certain period. For such cases it is necessary to have insight on path redundancy, i.e. what is the number of paths that connect any two nodes in organizational network. By increasing this number, organization is more stable and can withstand removal of an employee from organization. According to previous analysis of organizations we expect path redundancy to be greater in more expensive organizations, which introduces additional personnel through which communication is increased. These include line-and-staff, project and matrix organization. In research of redundant paths we also include how removal of a link between two nodes, or interruption of communication between two employees, will affect the average path length for whole network or time to transfer information between any two employees. The results for the dependence between the removals of links and the average path length for the line organization are given in Figure 6 (left). We can see that elimination of a random link can sometimes mean more than 5% more expensive communication or 5% more time for communication between any two employees in line organization. Also, removal of some links can cause disconnecting the entire network in unconnected clusters, so we find the percentage of links that disconnect the network. We also assess betweenness of those links in correlation with maximum edge betweenness for the network and we found that connections that disconnect network are influential links in entire organizational network (Figure 6 - right). Such connections is important to maintain because their removal would cause disruption of normal functioning of the organization and these are links that do not has redundant paths. In line organization, removal of 9.23% of communications between employees can cause disconnected organization, and 83.33% of these links have betweenness greater than 50% compare to the largest betweenness for edge for the whole network (Figure 6 - right).

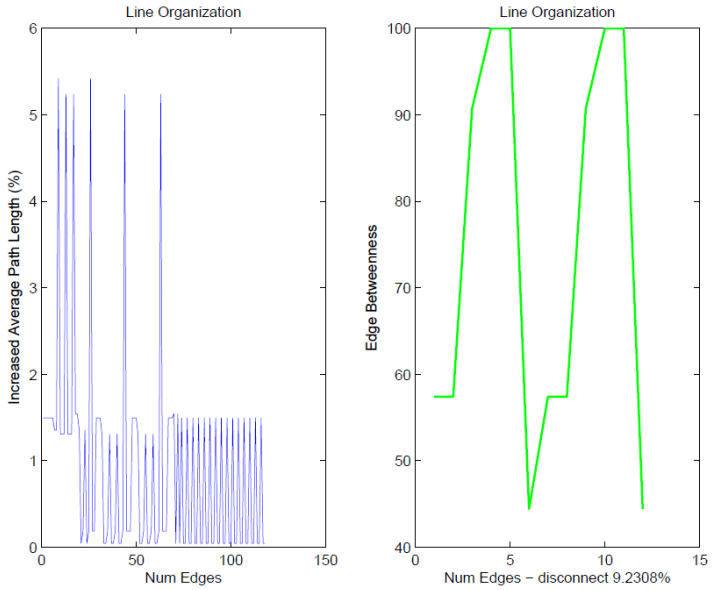

Fig. 6. Dependence of the average path length for the whole organization after interruption of communication between two employees (left). Percentage of links that disconnect the network and betweenness of those links in correlation with maximum edge betweenness for the network (right).

4 Conclusion

This brief has studied structure and relationships between employees in line, functional, line-and-staff, project and matrix organizations. We give short overview of what are different types of organizations and their characteristics. Afterwards, we give proposal of network measures and analytical procedures for modeling each type of organization. These network measures provide tangible image of organizations, because they quantitatively define connection between nodes and structural properties of organizations, and results obtained from network measures are reflected on real functioning of organizations. Obtained results confirmed proposed models and network measures, algorithms and properties of complex networks, which are applied over models to be able to depict real work of organizations. According to results and characteristics of different types of organizations may be noted that basic characteristics of each organization are confirmed, meaning that the design of various organizations is successfully done.

Future work should include improving or expanding of existing models. Because of specific interaction between employees in organizations, in many of networks is not just enough information for connectivity with other nodes, but also is needed a quantitative measure of interaction. For that purpose in future will be proposed several algorithms to provide weights of connections that are based on properties of organizational networks. Future work also will include analysis of dynamic properties of organizations and how they change when structure of organizations is changing.

5 Acknowledgment

LK thanks ONR Global (Grant number N62909-10-1-7074) and Macedonian Ministry of Education and Science (grant 'Annotated graphs in system biology') for partial support.

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