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Abstract

Taking an information-processing view of organizations, we address the need for building a robust set of performance measures for Edge Organizations (EOs). Alberts and Hayes in *Power to the Edge: Command, Control in the Information Age* conceptualized EOs as information-intensive entities whose performance is directly related to their ability for agile information processing. We ask the question, how can we measure the information-processing capacities of EOs? To this end, in this research-in-progress paper, we examine (1) the technical dimension of information flows, (2) the human-dimension of information flows, and (3) the socio-technical dimensions of information flows. The technical dimension represents movement of information between two machine nodes and can be informed by drawing on performance measures for telecommunications network theory. The social dimension represents the movement of information between two human nodes for which we examine the literature on social networks for performance measures. Finally, the socio-technical dimension represents movement of information between human and technical nodes or vice versa. To develop measures for these information flows we must not only extend, and customize, the performance measures from telecommunications networks and social networks, but also draw on measures in the disciplines of decision sciences, information sciences, and organizational science, among others.

Keywords**:** Edge Organizations; Information-Processing; Telecommunications Theory; Network Theory; Social Networks; Information Organizations; Command and Control

Introduction

Edge Organizations (EOs) as conceptualized by Alberts and Hayes in *Power to the Edge: Command, Control in the Information Age* (2003) are information-intensive organizations. The EO represents a fresh conceptualization of how a defense establishment should be organized. The EO has several desirable characteristics when compared to traditional hierarchical structures for command and control (C2). EOs connect nodes or entities using a peer-to-peer structure enabling easy movement of information. The timely movement of information among the peers increases the level of situational awareness resulting in operational efficiencies in time-critical scenarios. Typically, hierarchies have higher degrees of centralization and lower matrix strength (i.e., average degree of connectivity per node) in contrast to EOs that are more peer-to-peer in nature, with higher degrees of connectivity. Hierarchies are also more cumbersome to set up and mobilize than peer-to-peer arrangements. Finally, hierarchies are ideal for static or slowly changing environments where the large infrastructure cost of set-up/creation is amortized over organizational lifetime in terms of economic efficiencies of reuse and lower transaction costs. Peer-to-peer structures, on the other hand, are more suitable for dynamic environments where occurrence of repeat conditions or situations is low, thereby placing a premium on organizational agility. Clearly, the novelty and advantages of EOs for dynamic scenarios has led to an upsurge in interest regarding further exploration of their properties and potential for transforming age-old organizational structures like hierarchies.

Notwithstanding all the interest, we must acknowledge that EOs are no panacea for C2 and have limitations (see Scott 2006; Desouza, 2006a; Nissen 2005). For instance, as Desouza (2006a) noted, EOs assume that peers are capable of processing multiple forms of potentially dissimilar (and sometimes conflicting) information, in very short time intervals. If all such information is to be moved to the peers at the network edge, then all nodes must possess identical processing and cognitive capacities to process such heterogeneous forms of information, leading to significant network overhead. Otherwise, information distortion might occur due to varying levels of processing power. Further, EOs as proposed by Alberts and Hayes (2003) assume that decision-making authority can be distributed to the peers. This is not a realistic assumption nor is it judicious in many scenarios where edge nodes only have limited information. Pure EOs—where all peers are identical in capabilities and are fully connected—do not scale well without some form of hierarchy in connectivity. In other words, peer-to-peer connectivity is typically attained with network integrators such as hubs, bridges, or routers—otherwise network efficiency degrades and management becomes infeasible as the number of nodes increase. This brings into question the applicability of pure EOs for large settings, such as the Department of Defense (DOD), and even many of its constituents units, who are by no means small themselves (e.g., Department of Army or Defense Intelligence Agency). Additional critiques of the edge organization can be found in the writings of Scott (2006) and Nissen (2005, 2007). Scott (2006) raises a number of salient points, among which are the issue of applicability and interoperability. Should all DOD engagements and entities call for edge designs? The answer is no. Moreover, can EOs operate seamlessly with other organizations that might be designed as hierarchies? Unless an EO can operate in a networked and collaborative space, with coalition organizations its value and operations will be compromised. How should an EO, and more importantly can a pure EO, work in a collected setting remains untested and questionable. These are just a few of the critiques and challenges of the current conceptualization of EOs.

As noted by Nissen (2007, pg. 61), "scholarly research in the C2 domain remains divergent, and a noticeable chasm exists between well-established research and continuing C2 practice." Nissen (2007) was concerned with bridging C2 practice with the extant literature in contingency theory. Nissen (2007, pg. 63) writes "the problem…is that most military C2 researchers do not appear to build firmly upon the scholarly literature in these [Decision Making, Leadership, Management, Organization Studies, Social Psychology] other, applicable domains…, and it is rare for scholars in these other domains to focus on military C2...." Nissen (2007, pg. 64) goes on to make a critical point, "'inside' scholars within the military …do not appear to have drawn upon 'outside" scholarship in their independent conceptualization of concepts." Similar to Nissen (2007), in this paper, we are concerned with bridging C2 practice with the literature in telecommunications network theory and social network theory. By appreciating the extant work on performance measures in these literatures we can develop creative, and useful, measures for C2 and socio-technical networks in general. Moreover, the examination of research in the telecommunications and social network literatures will help us better understand the governing dynamics of information networks, which are the underpinnings of C2.

In this research-in-progress paper, we report on our ongoing work that seeks to build performance measures for EOs. Our research takes an information-processing view of organizations (Arrow, 1974; Choo, 1998; Desouza and Hensgen, 2005; March and Simon, 1991; Galbraith, 1974). The performance of EOs, like most other organizations, is dependent on their information management capabilities. Hence, research is needed to calibrate reliable and functional measures that provide us indicators of information processing capabilities. To this end, we examine (1) the technical dimension of information flows, (2) the human-dimension of information flows, and (3) the socio-technical dimensions of information flows. The technical dimension represents movement of information between two machine nodes and can be informed by drawing on performance measures for traditional (telecommunications) network theory. The social dimension represents the movement of information between two human nodes for which we examine the literature on social networks for performance measures. Finally, the socio-technical dimension represents movement of information between human and technical nodes or vice versa. To develop measures for these information flows we must not only extend and customize the performance measures from telecommunications networks and social networks, but also draw on measures in the disciplines of decision sciences, information sciences, and organizational science, among others.

The paper begins with a brief sketch of our conceptualization of information organization. Next, we provide an overview of performance measures from telecommunication network theory and their implications for designing EOs. This is followed by an exposure to the literature on social network analysis to address the human dimension of information flow in organizations. Concluding the paper, we provide our plan to build measures for socio-technical networks, especially those that have severe information-processing requirements like EOs.

Information Organizations

Organizations are essentially information processing entities (see Arrow, 1974; Choo, 1998; Desouza and Hensgen, 2005; March and Simon, 1991; Galbraith, 1974). The performance of an organization will depend on how effectively and efficiently it processes information from its internal and external environments and applies the information towards realization of its goals and objectives. As noted by Desouza (2006b), an agile organization will be able to (1) sense signals (data) in the environment, (2) process (construct information) them adequately, (3) mobilize knowledge-based resources and processes to take advantage of future opportunities, and (4) continuously learn and improve the operations of the organization. In addition, an agile organization will undertake the preceding activities in quick time cycles and with minimal cost and effort. Optimal information processing is a critical element for building agile organizations.

Information processing can be defined as the collection of activities involved with the creation, processing, transfer, storage, retrieval, and application of information (including receiving feedback). Desouza (2006c) drawing on the semiotic lens (Peirce, 1931–1935, 1958) defines information management as:

> "The collection of activities involved in managing the sources of information, analytics used to derive relationships from information, mechanisms for interpreting meanings from relationships, and calibrating actions based on meanings, in an effective and efficient manner, to meet the challenges of the organization. The components, sources management, analytics management, interpretation management, and action management, are in escalating order of dependence as each determines the basis upon which the others will build sequentially. The components of information management are linked with one another in a circular manner. The goals of information management are to contribute to increased business value of the organization and also to improve the process of information management in the organization."

The above definition is comprehensive in that it covers the peculiarities of information management from the sources from which signals are gathered to the actions that are calibrated from the processing of information and the generation of actionable knowledge. The components of information management are placed in order, albeit in a circular manner. For example, without good sources management, you cannot go on to have proper analytics management. The same is true as you ascend in order through the different levels of management all the way to actions management, which is dependent on the three levels below it. Ultimately, actions generated will influence the sources of information. In order for an organization to have a successful information management program, it must show proficiency in each one of the four components. Because of the interdependence each component has upon one another, failure at any level will result in a deficient information management program. Taken in combination, the four components represent the information management process from generation of information to the application of knowledge through the calibration of actions and learning from the actions so that this feedback may be used to improve successive activities in each of the components.

Central to the ability of an organization to conduct information management is the ability to transfer (also known as mobilize, route, move, disseminate) information between agents and objects. The transfer of information between two objects (e.g., computer devices) can be thought of as the technical dimension. Similarly, the transfer of information between two agents (i.e., human agents) can be thought of as the social dimension. We can also have a mixed-pair transfer, i.e., transfer of information between agents and objects or vice versa; this can be denoted as the socio-technical dimension. The transfer of information, of any kind, is determined by the existing infrastructure (also called network) that connects the various agents and object. Hence, one might argue that to truly build agile information organizations, like an EO, we must pay particular attention to the governing dynamics of information transfer. After all, it is the transfer of information between the various entities *within* and *across* the organization that will lead to the creation and execution of appropriate response, both proactive and reactive, to changing conditions in the environment.

We fully support, and embrace, the call by Nissen (2007) for more thoughtful research into C2 practice. As noted by Nissen (2007), too often C2 researchers and practitioners fail to embrace extant literatures that might inform their work. Nissen (2007) noted the lack of appreciation for the literature on contingency theory (Burns and Stalker, 1961; Lawrence and Lorsch, 1967) by Alberts and Hayes (2003) when conceptualizing organizational forms and concepts for EOs. In our review of *Power to the Edge: Command, Control in the Information Age* (Alberts and Hayes, 2003), we noticed a neglect of the extant literature on telecommunication network theory, social networks, and even information science. Specifically, the conceptualization of the EO rests on several fundamental assumptions on how information can be transferred between agents and objects. Hence, it is imperative that we pay attention to the literatures on telecommunications networks and social networks, which may point us to interesting findings on the dynamics of information flows between technical and human nodes, respectively. Moreover, we should take the findings in these literatures as a starting point and advance them to build measures for socio-technical networks such as EOs. The goal of our research project is to do just that.

Telecommunication Networks: The Technical Dimension

In this section, we seek to provide a brief overview of the main attributes of telecom networks: the topology/structural aspects as well as performance criteria that drive such network design (the interested reader is referred to Schwartz [1987] and Van Mieghem [2006] for an introduction to performance measures for technical networks). The primary objective is to seek areas of convergence and divergence between the theory developed for telecom networks and the new principles needed for modeling C2 organizational operations as networks. Traditional analytical approaches consist of using graphs[2] to represent networks; this allows the rich mathematical tools of graph theory to bear onto this problem.

The primary function of telecommunication networks is *transport of information* between any source-destination pair; each such route or path through the network represents a 'flow'. Any telecom network design seeks to achieve such transport *reliably and efficiently as a function of network size* (i.e., as the network scales both in physical expanse or coverage as well as the number of nodes per unit area). What makes network design challenging is that it is inherently a *multi-objective optimization* wherein the interactions between the various objectives necessitate key trade-offs (i.e., increasing one dimension may monotonically decrease another).

The traditional metrics of any network can be broadly classified as: a) *throughput,* b) *delay* (the 'efficiency' dimensions), and c) *packet loss* (the `reliability' dimension). Further, any network

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[2] A graph consists of a) nodes or vertices connected by b) links or edges. Depending on the directivity of the information flow, a graph can be directed (set of directional only links) or undirected (supports bi-directional flows).

performance is a strong function of the network *topology*, i.e., any of the above metrics depends on not just the number of network elements but also details of their inter-connectivity.

To obtain some intuitive understanding of these trade-offs, consider throughput which is defined as the number of packets successfully transported by the network (end-to-end between source-destination pairs, each of which constitutes a *flow*) per unit time. Clearly, it is desirable that the aggregate throughput (sum of throughput of all the simultaneous flows) be as large as possible as a macroscopic indication of network health. However, this does not guarantee whether any *particular* flow achieves a desired level; in fact, it is common that aggregate network throughput can be maximized with only a few flows sharing the bounty, and many others are starved. As networks scale in density of users, the interference between simultaneous users/flows imply that packet losses increase, which in turn reduces the aggregate throughput. In the context of C2 operations, and especially in the conceptualization of EOs, research must be carried out to examine how throughput is impacted in a fully connected network, especially when information is not being pushed at regular intervals, but can be dynamically pulled on an ad-hoc basis. Issues such as which information element gets priority and which flows override others are non-trivial and can severely impact the throughput outcome.

Further, today's networks must support different types of information—voice, video and data—that have different tolerances to loss/distortion and network delays. Typically voice is more robust to packet losses (because some missing data can be 'interpolated' or recovered) but not to delay (delays over 50 msec essentially render a correct voice packet useless), whereas data applications such as email are much more delay tolerant but require a much higher fidelity. In other words, network design for different *types* of information (voice, data, video, etc.) must include *differential* objectives, which may be achieved by *class-based prioritization.* There are many ways to enhance reliability of data transport in a network, notably via use of coding (redundancy in the information stream sent such that some errors may be corrected at the receiver) and/or use of diversity (sending multiple copies, whether simultaneously in space over different routes or in time—e.g., by retransmission). However, such reliability exacts a price, notably in terms of *end-to-end delays*[3] that impact the timeliness of information. Services are thus often classified as real-time or non-real-time based on the ability of the network to support end-to-end delivery to meet strict delay constraints (for voice and video traffic). A critical tenet of the EO conceptualization is the ability for one to take advances in richness in bandwidth and fully-connected networks. Alberts and Hayes (2003, see pages 74–83) analyze the changing nature of telecommunications by a comparative analysis of telephone exchanges, broadcast exchanges, email exchanges, and the characteristics of fully-connected networked environments. However, they do not acknowledge the challenges associated with moving multiple forms of information, across a single or multiple networks, to peers, who may have varying capacities for information processing and varying needs (priorities) for information. As we highlight above, a critical examination of how differential priorities will impact information transfer is warranted. Moreover, one must examine network performance given the varying forms of information that require transport, the capacities of the nodes to process these varying forms of information, and also the routing capabilities of the network to handle conflicts in an intelligent manner.

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[3] For example, retransmissions are often limited because they incur round-trip delays between the node pairs. Hence unreliable links that lead to retransmissions in turn contribute to increased end-to-end delays.

The other important factors that impact network throughput and delay may be classified as "structural," on which we focus next. Network topology—which is typically captured via graph models—provides a macroscopic view of node connectivity, and in turn, is the basis for creation of routes or flows through a network. Thus structural properties of networks, e.g., the number of neighbors a node has (captured by the "degree" distribution of a graph) provide insight as to number of flows that can be simultaneously supported by a network, while "network diameter" in relation to a single hop indicates the (average) length of a flow. As the number of hops or links that constitute a flow increases, so does the end-to-end delay because of the congestion at intermediate nodes; many flows share common nodes implying queuing and processing delays. In rare instances, buffer overflows at nodes may occur due to queue build-up, leading to loss of information.

The notional hierarchy shown in Fig. 1 has some distinguishing characteristics, prominent among which is the existence of `tiers' that channel flow of information upwards, implicitly establishing a value ordering. For a pure hierarchy of n nodes where each parent node has b leaf (or child nodes), the depth (or number of tiers) in the hierarchy equals $\log_b n$, which is also the maximum number of hops required by information from a node at the lowest tier (edge) to reach the organizational core. Fig. 1 shows an example for b=2, n=6 that results in 3 tiers.

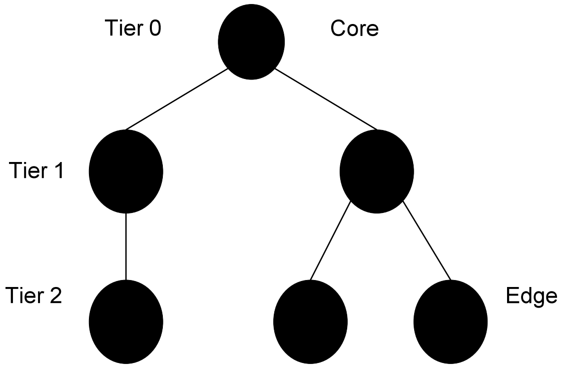

Fig. 1: A Pure Hierarchy with n=6 nodes (multi-hop)

In contrast, an edge network is (in its purest form) *fully connected*, i.e. there exists a direct link between any two node pairs (see Fig. 2). Such a network topology is completely non-hierarchical and comprises nodes with identical capabilities and responsibilities (i.e., an ideal "democracy"). The benefits of such a network include: *robustness to link failure.* This is an extreme presumption which would imply that for a network of n nodes, the number of links equals $\binom{n}{2} \approx n^2$. While this may be feasible for small n, it becomes increasingly infeasible as n increases. Put in another way, an idealized fully connected network is not scalable from an operational or managerial perspective.

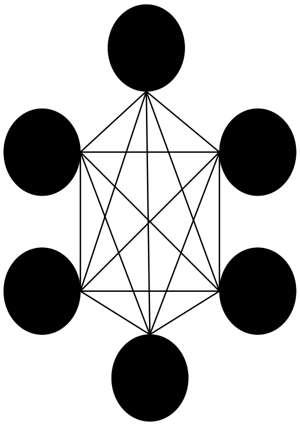

Fig. 2: A Fully Connected Edge Organization with $n = 6$ nodes *with direct information flow between any two nodes*

In reality therefore, networks have multiple hops between node pairs, which in turn limits the achievable end-to-end *information rate*. Multiple hops call for intermediary processing of information as it traverses the network. This may result in loss of information, information delays, and information distortion, among other undesirable characteristics. For example, in the fully connected network in Fig. 2, the maximum[4] (and mean) path distance measured in number of hops equals 1. However, as some of the links are broken while maintaining full connectivity (i.e., there exists a path between any two nodes), the maximum (and mean) path lengths increase. It is relatively easy to see that if n nodes are distributed over a fixed planar area (assuming unity for convenience), then the mean inter-node link distance is $\propto \frac{1}{\sqrt{n}}$ and the network diameter is $\propto \sqrt{n}$. Hence, while designing EOs, we must be wary of the appeal of a fully connected network. Not only are these network forms costly in terms of overhead but may not offer us the desired outcomes. For example, a critical assumption of these fully connected networks is that each node is similar to every other node. Put another way, there is no difference in the processing capabilities of each node. Hence, information flows are determined by the quickest distance and minimum hop criteria. This is a very unrealistic assumption. We know that in the context of C2, it is impossible, and a fallacy, to assume that we are going to have nodes that have equal processing capabilities. Realizing this ideal state would require a complete revamp of the DoD infrastructure, which is not feasible. Hence, the question becomes what is the ideal network design given the benefits (and limitations) of both hierarchical and edge designs?

Another important attribute of networks is their information capacity, defined as the maximum rate that can be supported by a node. Results in network theory suggest the network diameter has a significant impact on network capacity. In general, increasing network diameter implies reduced node capacity. For edge (peer-to-peer) networks, the node capacity is $\propto \frac{1}{\sqrt{n}}$; this result suggests that in terms of information flow, only small scale pure edge networks are effective (and capacity is seriously affected for wide-area peer-to-peer networks). This gives further

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[4] The maximum path length in the network is called the diameter.

credence to consideration of hybrid networks that possess both mesh and hierarchical characteristics.

As can be inferred from the above discussion, both extreme networks have significant performance concerns. We hence argue that there is a need to design and test new structures that have the potential for enhanced performance as well as flexibility. So what might these structures look like? We may draw on developments in the arena of mobile ad-hoc wireless networks.

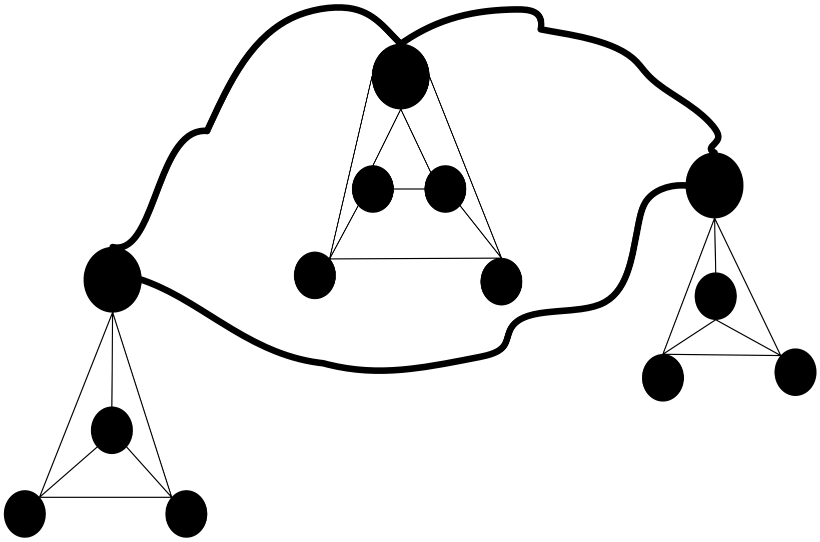

Fig. 3: A Two-Tier Hybrid Network: 10 tier-1 nodes (small), 3 tier-2 nodes (large)

Fig. 3 shows a simple two-tiered network to drive home the potential of combining elements of peer-to-peer (edge) and hierarchies. Note that the large nodes are symbolic of information centers where signals (or data) are aggregated from the tier-1 nodes—there are thus m clusters of tier-1 node, each with their respective tier-2 aggregation points. The tier-2 nodes are themselves inter-connected by “longer” paths denoting greater signal strengths, commensurate with resources at these tier-2 nodes. It is clear that the network diameter is now m; however the cost lies in the increased vulnerability of such hierarchies in case a tier-2 node is compromised. Some initial results suggest that $m \square O(\log n)$ is a good choice, leading to reduction in network size (compared to $\sqrt{n}$ diameter of mesh networks) and hence enhanced capacity but at the cost of (significant) reduction in network robustness. For example, the network in Fig. 3 is more susceptible to link failures in tier-2 due to larger degrees for tier-2 nodes. We readily see that such a hybrid family potentially includes the structure of scale-free networks that consist of a few nodes (hubs) with large degrees and many others with smaller degrees.

To summarize, an examination of the performance measures in telecom network theory points us to several interesting research issues. It is clear to us a deeper investigation is warranted to analyze the performance of EO type information networks for the routing of information between technical nodes. We now turn to the social dimension that encompasses the movement of information between two human nodes within a network.

Human Networks: The Social Dimension

One of the most severe limitations of the conceptualization of EOs is that is does not pay due attention to the literature in social network analysis (see Wasserman and Faust, 1994; Berkowitz, 1982; Burt, 1982; Milgram, 1967; Mitchell, 1974). We believe that a critical examination of the social network literature can inform C2 practice on the peculiarities of information flows among the wide-range of C2 actors. The interested reader is referred to Wasserman and Faust (1994) and Freeman (2004) for a detailed introduction to social network analysis. For our purposes, we will focus on outlining a few concepts in social networks and their implications for the design of EOs.

Social network analysis is concerned with the study of relationships among interacting units. Put another way, repeated patterns of interaction create network structures that represent the core artifact in social network analysis (Wasserman and Faust, 1994; Milgram, 1967; Wellman and Berkowitz, 1988). As noted by Wasserman and Faust (1994, pg. 5), "the unit of analysis in network analysis is not the individual, but an entity consisting of a collection of individuals and the linkages among them. Network methods can focus on dyads (two actors and their ties), triads (three actors and their ties), or larger systems (subgroups of individuals, or entire networks)." Social networks are represented as sociograms (Moreno, 1953), which are two-dimensional diagrams that depict units and relationships among them.

Certainly, the study of networks, especially information networks, will represent a larger systems analysis in the context of social network analysis. Social network methods have been applied to a range of problems. Of interest to the C2 literature are the applications of social network analysis to collective decision-making (Leavitt, 1951), exchange and power structures (Cooke and Emerson, 1978), and community relations (Wellman, 1979), among others.

In the context of C2, we must remember that a large part of the actors in the C2 setting are humans. Humans are social beings. As such, they have a tendency to form groups, exchange information through informal settings, choose the information sources they trust, and interact in other peculiar manners which are not standard or predictable. Moreover, not all information exchanged within a C2 arena will flow through technical challenges. It is likely that the use of informal channels will be as prominent, and in some cases, even more important than formal channels. Hence an understanding and appreciation for the social dimension of information transfer is important. In the context of EOs, this appreciation is even more critical as the central premise of EOs is the distribution of information to the edges of the organization. The distribution of information, as noted by Alberts and Hayes (2003), is one that is based on a "pull" (on-demand) mechanism rather than the traditional "push" mechanism. Social networks represent a powerful resource from which agents may be able to pull information from sources, both formal and informal, that they trust and have an affinity for.

Social network analysis is focused on the study of the structural properties of networks. Hence, the performance measures that are most often studied in these settings are of a structural nature. A few of the common measures in social network analysis are: *betweenness, closeness, centrality, eigenvector centrality, centralization, clustering coefficient, cohesion, reach, structural cohesion, structural equivalence, path length,* and *radiality*, among others (see Wasserman and Faust, 1994, for details). In this brief paper, it is not possible to delve into details of each of these measures. Table 1 contains a summary of social network measures and their implications.

Insert Table 1 Here

Social Network Measures and the Impacts on Information Transfer

The impacts of social network measures (see Table 1) on information transfer are assessed from two perspectives: (1) the components of the information transfer activity—source, recipient, channel/context, and the information; and (2) the outcomes of information transfer—the patterns and extent of effects.

The first perspective intends to focus on the quality of information transfer, in other words, to specify the performances to be measured. Sources and recipients amount to the nodes in a network, so their positions and influences may be more appealing to us. Channels and context correspond to relations and the entire network, respectively, and they are featured by distance and density. Specifically, the "quality" of information transfer in a network environment is projected to the components as follows:

- Actors (sources and recipients): (1) influence: replacability, visibility/popularity, controllability, vulnerability (tend to be attacked), trustworthiness, and authority; (2) positions and roles in the information transfer
- Channels: efficiency, safety, stability, controllability, replacability, vulnerability (tend to be attacked)
- Context: robustness/adaptability/flexibility, completeness (any isolates ?), extent of centralization, cohesion (easy or hard to split)
- Information: distortion, delay

The second perspective focuses on possible changes in the quality of information transfer due to the use of certain performance measures, for example, will there be any long-term influence if we use this measure of performance? Will it cause any changes to the nature of the information being transferred?

Centrality—Measures for Actors

This category of measures describes the extent to which an individual actor occupies a central position in the network in one of the following ways: having many connections with other actors (degree centrality), being able to reach many other actors (closeness centrality), connecting other actors who have no direct connections (between centrality), or having connections to central actors (eigenvector centrality).

Degree centrality: (1) An actor with a high degree centrality should be recognized as a major transfer point of information flows. (2) Since it has many alternatives, such an actor is relatively independent of the control of others, and resistant to information delay or distortion; however, there is a problem of information overload or conflicting. (3) This measure tells us nothing about the knowledge or information the actor has. A peripheral actor could be the one whose knowledge we desire.

Closeness centrality: (1) An actor with high closeness centrality can interact with all others at low resource cost (time, expense, etc.) and information distortion. (2) If the length of path is defined by the number of direct ties it contains, an actor with high closeness would be an excellent monitor of the information flow in the network—they have a good "view." (Wasserman and Faust, 1994)

Betweenness centrality: (1) An actor with high betweenness centrality also controls the channel resources of information transfer and hence tends to be attacked, but it may not control the knowledge or information resources. (2) It can play the role of a coordinator or a third party in information transfer. The change in these actors may influence the information transfer between the source and the recipient (may have to choose another path). (3) This measure is useful in the assessment of the efficiency and control ability of channels. (4) This measure is a sensitive indicator of important changes in the network topology.

Eigenvector centrality: (1) This measure assesses the efficiency of information transfer based on a combination of the centrality of actors and the efficiency of channel; the idea is to reach more of the network with fewer efforts. (2) This measure assesses actor centrality from a global, network-wide perspective instead of a local, relationship-based perspective.

Radiality: (1) This measures the extent to which an actor's social relations can help other actors to build relations. For example, an actor who has direct connections with others without direct connections among them will get higher scores than an actor who has connections with others with direct connections among them (Valente and Foreman, 1998). (2) Actors with high radiality will be good connectors during information transfer, since they help to access information beyond direct ties.

Centralization—Measures for Context

This category of measures describes how variable or heterogeneous the individual centralities are, i.e., the extent to which some nodes have high centrality, while the others, low centrality. All measures in this category can be used to distinguish a centralized network, which has many of its ties dispersed around one or a few nodes, with a decentralized network, in which there is little variation between the number of ties each node possesses. They measure the robustness of information transfer: a very centralized network is dominated by one or a few very central nodes, which can become a single point of failure in that if they are removed or damaged, the network quickly fragments into unconnected sub-networks. Conversely, a less centralized network is resistant to many intentional attacks or random failures—many nodes or ties can fail while allowing the remaining nodes to still reach each other along other network paths.

Difference between the measures of centrality and centralization: (1) The measures of centrality are individual-level. The measures of centralization reveal the overall network structure based on the centralities of all nodes, allowing us to compare different networks. (2)

The measures of centrality describe the extent to which a single node is central in the network. The measures of centralization actually describe the dispersion of the network.

Difference between centralization and density: These terms refer to different aspects of the overall “compactness” of a graph. Density describes the general level of cohesion in a graph; centralization describes the extent to which this cohesion is organized around particular focal points.

Subgroups

This category of measures shows how a network can be partitioned based on the cohesion among group members represented by the properties of the ties connecting them. They also provide us a way to build a hierarchical view of the network based on the embedded extent of different subgroups.

Measures for subgroups based on adjacency

Clustering coefficient: (1) Actors within a clique share high trust and affinity, and the information channels are efficient and safe. Therefore, the higher the value of this measure, the better the quality of information transfer within the subgroup and, probably, the more information transfer will happen inside than outside. (2) The resulting changes in the differences between within the group and outside the group may trigger certain responses from outside (e.g., intervention, control, or efforts to split the group). (3) Every group member will become more “central” with regard to the entire network but less “central” within the group.

Measures for subgroups based on geodesic distance

Network reachability: (1) If two actors are reachable, information can be transferred between them.. (2) This measure is related to the “small-world network,” in which most nodes are not neighbors of one another, but most nodes can be reached from every other by a small number of hops or steps.

Measures for subgroups based on the number of ties connecting two nodes

Structural cohesion: (1) A big value of this measure indicates a cohesive subgroup with high channel redundancy, in which the information transfer is robust and the minority control of resources is difficult. (2) The value of this measure increases with the addition of independent paths (channels for information transfer) to the network. (3) The process of removing members from a group amounts to a process of identifying the most fragile/critical/powerful actors in a network and a process of reducing the robustness of the group. (4) We can monitor the critical actors instead of the whole group for changes in robustness. (4) Highly cohesive groups are nested within less cohesive groups, and their members are more difficult to remove concerning the number of relationships they get involved in (Moody and White, 2003).

Measures for subgroups based on comparison of ties within the subgroup to ties outside the subgroup

Cohesion: (1) This measure involves not only the information transfer within a group, but also that between a group and its environment and probably another group. (2) This measure may reveal some differences in the strength or frequency of ties within the subgroup and outside the subgroup, for example, Granovetter’s “the strength of weak ties” theory (Granovetter, 1982), which proposes that information spreads rapidly through densely knit subgroups because actors are strongly connected to one another and they directly share the information, while access to new information, however, comes into strongly connected groups through sources with external connections, which are likely to be weak.

Roles and Positions[5]

This category of measures deals with subsets of actors who get involved in similarly structured relations. Since position is based on the similarity of ties among subsets of actors, rather than their adjacency or reachability, this concept is quite different from the notion of cohesive subgroup. Actors occupying the same position need not contact with one another (Wasserman and Faust, 1994).

Structural equivalence: (1) while two actors may have direct connections to totally different individuals, the type of relations that they have with these others may, nevertheless, be similar; the two actors are substitutable for each other. (2) Social positions involve more enduring and more stable relations that are reproduced over time (Scott, 2000).

Given this introduction to social network measures, let us take two of these measures and demonstrate how they might apply to C2 design decisions, and in particular the concept of EOs.

Consider *path length* defined as the distance between the pairs of nodes in the network. The greater the *path length,* the longer it will take information to flow between two nodes. Moreover, the greater the *path length*, the greater is the chance of information distortion, because distance does matter in human networks, and there might be multiple bridges or interferences that may delay or distort a given message. In the conceptualization of EOs, the notion of *path length* is treated in a simplistic fashion. In *Power to the Edge* (Alberts and Hayes, 2003), the distance between two nodes is constant and each node is equidistant from any other node. This is a very simple, but unrealistic, assumption. Nodes are constantly moving and the distance between nodes will vary. For instance, the distance between Command Sergeant Majors and the Sergeant Major of the Army will be significantly less than the distance between the Sergeant Major of the Army and a Private. Moreover, an individual at the lower hierarchical ranks of the army is expected to move, vertically or hierarchically, more often than his/her counterparts at higher levels. Research is need to test the effects of varying distances between nodes in terms of outputs for information delays and also the fact that a given percentage of nodes (especially those at the lower levels, i.e., those with lower processing power/capabilities) can be more easily dynamically reassigned than their superior counterparts.

Now consider the concept of *centrality*. Centrality is defined as the number of ties to entities in the network. *Eigenvector centrality* is used to identify the importance of a node to a network. It is calculated by assigning a relative score to all nodes in the networks based on the connections they possess. The greater number of connections a node possesses, the more valuable it is to the network. Another related measure is *closeness* defined as the degree to which an entity is near all other entities (either through direct or indirect ties). In social network analysis, these measures

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[5] Position refers to a collection of individuals who are similarly embedded in networks of relations, while role refers to a collection of relations that link social positions and associations among these relations.

are analyzed to understand the relative importance of nodes in the network. A highly valuable node may not always be a good thing. For instance, if a node is very valuable, that could mean information sent to this node, via its counterparts, may be delayed before being processed due to the cognitive limitations of the nodes. Similarly, the loss of a valuable node may disrupt the underlying structure of the network and may render nodes unconnected. Hence, we may want a network where all nodes are equally important, a truly democratic setting, in which no single node may be able to exert significant influence over the structure of the network.

In the context of EOs, the measure of concept of centrality has important implications. Alberts and Hayes (2003) assume that nodes in the networks have equal processing capabilities and can handle multiple forms of information. This becomes the basis for asserting that information can be pushed to the edges, thereby raising situational awareness and a shared understanding of command and intent. This assumption is academic and does not resemble reality. In the DoD, like any other C2 structure, not all nodes are equal or similarly valuable. For instance, it is impossible to assume that a Private (in the Army) will have the same capabilities as a Sergeant Major of the Army or a Lieutenant General. The Private would need to acquire experience and expertise, show competency in his/her skills, and be promoted several times before they reach the rank of Sergeant Major. In any army, the number of individuals decreases as we move through the hierarchical levels. For instance, the number of Privates would be more than the number of Master Sergeants and the number of Sergeant Majors would be lower than the number of Master Sergeants. Some issues that need further examination include: What would happen if we treat nodes as belonging to set of different classes (e.g., Private, Master Sergeants)? For instance, if we lose a Master Sergeant versus a Private, can we reasonably assign the same cost functions and expect the same performance outputs? What would happen if the cost of replacing a lost node or adding new nodes (e.g., recruiting personnel) is not uniform across all classes of nodes?

As the above brief exposition of social networks shows, the discipline of C2, both research and practice, can gain from an examination of the extant models in this discipline. However, one must note that most models in social network analysis are *static*. They do not depict real-time progression of networks. For this, we must go beyond traditional social network analysis to dynamic network analysis (see Newman et al., 2006).

C2 Networks: The Socio-Technical Dimension

While the above description of network metrics have been structural, a purely mechanistic approach to understanding network behavior is only appropriate for purely electronic and social networks. Such models are points of departures for mixed networks with electronic and human agents; the lessons from electronic and social networks are valuable for providing *first-order* insights into the various trade-offs between key metrics (capacity, robustness). (1) Characterizing the human-centric aspects of networking by identifying the right metrics and (2) describing such network dynamics over time will constitute the thrust of the proposed research. Not all networks are optimized by the same parameters, and it is certain that hybrid networks with human agents will have objectives that are different from electronic networks.

According to Alberts and Hayes (2003), the choice of the correct C2 approach depends on warfighting environment, continuity of communications both vertically and hierarchically, volume and quality of information moving through the organization, professional competence of the forces at all levels of command, and the degree of creativity and initiative that decision-makers can be expected to exercise. In this paper, we have provided a glimpse into our ongoing work that is using telecommunications theory and social network theory to understand the implications of information transfer in EOs. As noted by Alberts and Hayes (2003), the continuity of communication and the volume and quality of information are important determinants of C2 arrangements. Hence, C2 researchers and practitioners are well advised to examine the technical and social dimensions of information flows and their associated performance impacts. This is a critical step towards designing the right organizational structure to allow for the most robust networked information environment.

The next step will involve building measures to test the performance of networked structures given varying conditions of war-fighting environments, competence of the nodes, and the degree of creating (dynamism) of the nodes in task completions. This will involve drawing on measures and models for the disciplines of decision sciences, information sciences, and organizational science, among others.

Drawing on Alberts and Hayes (2003) we are interested in technical measures that help us evaluate the performance of EOs across the following dimensions:

- *Robustness*: the ability to maintain effectiveness across a range of tasks, situations, and conditions;
- *Resilience*: the ability to recover from or adjust to misfortune, damage, or a destabilizing perturbation in the environment;
- *Responsiveness*: the ability to react to a change in the environment in a timely manner;
- *Flexibility*: the ability to employ multiple ways to succeed and the capacity to move seamlessly between them;
- *Innovation*: the ability to do new things and the ability to do old things in new ways;
- *Adaptation*: the ability to change work processes and the ability to change the organization.

We will approach this issue from the perspective of information transfer, which is central to the ability of an information organization. Specifically, the framework is based on the communication research of Shannon and Weaver (Shannon & Weaver, 1949). On one hand, each measure will be evaluated in terms of their relationships with the four elements of information transfer—source, destination, channel (network), and information, as well as their combinations. On the other hand, performances from all three levels of Shannon and Weaver’s communication model (technical, semantic, and effectiveness) will be discussed, with both quantitative and qualitative measures. We think there is temporal and bidirectional causality existing between performances at different levels. The use of technology gradually influences human beings, first as individuals and then as groups; then the experience or perception of human beings will inversely affects the use of technology. The interaction of different levels could be viewed as a kind of socio-technical communication involving both human and electronic agents.

Since performance measures from a specific discipline usually serve the purposes or missions of that area, the selection procedure will be conducted based on comparison. Answers to the following questions will be pursued: (1) (Macro) what are the primary missions of this discipline in terms of information transfer? Are they related with agility and quality? (2) (Micro) what are the typical actions of this discipline in terms of information transfer? Can these actions and their objects be mapped to the procedure and the elements of information transfer? *(Preliminary: what concepts in this area correspond to the four elements of information transfer and their combinations?)* (3) Are there any measures or categories of measures for each of the above actions and their objects? Which of them are related with agility and quality? (4) Are these measures purely technical, purely human, or hybrid? Is there anything similar to Shannon and Weaver's multi-level model which can distinguish technical and human measures? (5) Any other special facts in this area?

As an example, consider case of the telecommunications literature. The primary mission of telecommunication networks is to transfer information from source to definition efficiently (time and other resources) and reliably (information security, completeness, correctness). The dimensions of agility mainly involved are responsiveness, robustness, resilience, and flexibility. Other concerns include efficiency and reliability. The typical actions in telecommunication networks can be grouped as[6]: (1) channel-related: stop/discard, postpone/resume, routing[7], rank (priority), and share; (2) node-related: initiate/end (request/answer), accept/reject, identify, authenticate, and correct. The seven layer OSI (Open Systems Interconnection Basic Reference Model) model is a counterpart of Shannon and Weaver's model, where the lower layers are more technical and the upper layers are closer to users and applications. Special features of telecommunication networks include: (1) there are multiple layers, each with its own protocol. "Hierarchy" and "policies" guarantee quality, but may undermine agility. (2) The telecommunication network function as a protocol-based, highly automated technical platform and communication environment. (3) Information quality mostly depends on system quality. Accordingly, the following measures are selected from this area are shown in Table 2.

Insert Table 2 Here

This research will also probe the two important dimensions listed above: namely, the properties of resistance of such mixed (human-electronic), hybrid (edge + hierarchy) networks to various attacks. Specifically, we will use properties of affinity suggested by various theories of socio-economic contracts along with network simulation to arrive at constructive approaches to studying various network objectives, such as robustness to directed attacks. Further, we will investigate the role of evolution of affinities between nodes over time, which is necessary for understanding how such network properties evolve. To do this requires that we revisit various assumptions underlying the static (pure) edge and hierarchy. For example, the non-directed graph model assumed above uses a simplistic assumption: A link between a node pair exists (or does not) independently of all other links. In practice, it is well known that link correlation or

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[6] Only channels or nodes can act.

[7] The process of selecting paths in a network along which to send data or physical traffic

aggregation is a persistent phenomenon during the formation and growth phase of networks. For example, hubs are formed by a preferential model for link aggregation whereby nodes with a higher degree continue to aggregate more links. Further, the spatial dimensions of such aggregation (i.e., correlation between nearby links) on network structure have not been explored. Other associated aspects include the presumption of bi-directionality of links; in practice, links may be unidirectional (particularly in hierarchies) which is known to have significant impact on network properties. We anticipate the following primary outcomes:

- Performance measures for socio-technical information and knowledge networks.
- A family of designs for socio-technical information and knowledge networks.
- A deeper understanding of the design of command-and-control architectures and the role of information flow within entities in the network.
- A contingency framework outlining the applicability of various designs of socio-technical networks based on internal and external environmental conditions.

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Table 1: Social Network Measures[8]

#	Measure	Formal Definition	Interpretation	Range[9]	Relation Between Measures
1	Centrality				
1.1	Degree centrality	The degree of *V*, whether the lines are directed from it or toward it	To find actors who get involved in many activities	[0, *g*–1]	
1.2	Closeness centrality	The inverse of the sum of the distances[10] from *V* to all the other nodes in a network	To find actors who are close to all the other actors	[0, $(g–1)^{-1}$]; *max*: *V* has the smallest possible distance to all other nodes	Average path length[11] of the network decreases as the closeness centrality of all nodes grows
1.3	Betweenness centrality	The sum of *V*'s "betweenness" to all pairs of nodes (without *V*), where its "betweenness" to a pair of nodes is defined as the number of the shortest paths connecting that pair which pass through *V* divided by the number of all shortest paths of the pair	To find actors with much control over the interaction of other actors (they occupy an intermediary position on the shortest paths connecting other actors)	[0, (*g*–1)(*g*–2)/2]; *min*: *V* does not locate on any shortest path; *max*: the number of pairs without *V*	Does not necessarily have a positive relationship with degree centrality [12]
1.4	Eigenvector centrality	A proportion ($1/\lambda$) of the sum of the centrality (x_i) of all its network neighbors.	Take into consideration the centrality	(0, 1)	Increases with the degree

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[8] Notation: (1) Designate the node being measured as *V*, the pair of nodes involved as *Vi* and *Vj*; (2) *g* is the total number of nodes in the social network. Assumption: the underlying graph is non-directed, with every edge having a unity value.

[9] Different variants of the measures may have different ranges.

[10] Measured by the length of the shortest path between two nodes

[11] The average of all the path lengths in a network

[12] A node of relatively low degree may play an important intermediary role and so be very central to the network, e.g., a node in a circle graph

		It is determined by calculating $\lambda X = AX$, where $X = (x_1, x_2, \ldots)$ is the eigenvector of the network's adjacent matrix A with eigenvalue λ.	score of all other actors to which V connected		centrality of its network neighbors
1.5	Radiality	The radiality of the node Vi is defined as[13] (1 – diameter of the network + geodesic distance between the nodes *Vi* and *Vj)* / *g* – 1; *Vj* stands for every other node in the network	To find actors who send ties out in the network to provide paths for other actors, helping them to connect		Correlated with out-degree
2	Centralization				
2.1	Degree centralization	(the largest degree centrality of all nodes – the individual degree centrality of one node) / (g–1)(g–2); the denominator is the maximum possible value of the numerator		[0, 1]; *max*: one node directly connects all the other g–1 nodes, and other nodes only interact with this one; *min*: all degrees are equal	No linear relationship with degree centrality
2.2	Closeness centralization	(the largest standardized closeness centrality of all nodes – the individual degree centrality of one node) / {[(g–2)(g–1)]/(2g–3)}; the denominator is the maximal possible value of the numerator		[0, 1]; *min*: the lengths of all shortest paths are equal; *max*: there is one node whose every shortest path to other (g–1) nodes has a length of 1, and another node whose every shortest path to the remaining (g–	No linear relationship with closeness centrality

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[13] Here the geodesic distance is the length of the shortest path from *Vi* to *Vj*. The diameter of the network is defined as the maximum value of all these directed geodesic distance. If *Vj* is unreachable for *Vi*, then their geodesic distance is equal to 0.

				2) nodes has a length of 2	
2.3	Betweenness Centralization	**(**the largest betweenness centrality of all nodes **–** the individual degree centrality of one node**) / (***g* **–**1**)**; the denominator is the maximum possible value of the numerator		[0, 1]; *min*: all nodes have exactly the same betweeness centrality; *max*: the graph is a star graph	No linear relationship with betweenness centrality
3	Subgroup				
3.1	Clustering coefficient[14]	The proportion of ties between the nodes within *V*'s neighborhood (excluding *V*) divided by the number of ties that could possibly exist between them	To measure how close a node and its neighbors are from being a clique[15]	[0, 1]; *min*: no tie exists between any pairs of nodes that connect to *V*; *max*: every neighbor of *V* also connects to *V*'s every other neighbors	Has a positive relationship with the degree centrality of group members
3.2	Network reachability	The average number of people reached[16] per person in the network for a one-step process, two-step process, etc	To measure how easy it is for information to diffuse through the network		Increase with the growth of clustering coefficient
3.3	Structural cohesion	A group's structural cohesion is defined as: (1) the minimum number of members who, if removed from a group, would disconnect the group; (2) the minimum number of independent[17] paths	To measure the robustness of a subgroup in the network	[1, *g*–1], *min*: one path connecting all nodes; *max*: for g actors, there are almost as many (*g*–1) independent paths between	

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[14] The clustering coefficient for the whole network is the average of the clustering for every node.

[15] A clique in a graph is a maximal complete subgraph of three or more nodes, all of which are adjacent to each other, and there are no other nodes that are also adjacent to any member of the clique.

[16] If there is a path between two nodes, then the two nodes are said to be reachable.

[17] Two paths from *Vi* to *Vj* are independent if they have only nodes *Vi* and *Vj* in common.

		linking each pair of nodes in the group		each pair	
3.4	Cohesion	The average value of ties within a subgroup divided by the average value of ties from group members to outsiders	To measure the extent to which ties are concentrated within a subgroup rather than between subgroups	[0, $g(g-1)/2$]; *max*: the maximal possible number of ties in the subgroup, assuming it has g members	
4	Measures of Structural Equivalence[18]		(1) To find substitutable actors; (2) to identify uniformities that define social positions		
4.1	Euclidean distance	The Euclidean distance between the ties to and from the two actors; for actors V_i and V_j, this is the distance between rows i and j and columns i and j of the sociomatrix	"Distance" between two actors	The range is [0, $\sqrt{2(g-2)}$]; *max*: for a single directional dichotomous relation on which diagonal entries are undefined. If two actors are structurally equivalent, the value of this measure is 0. Otherwise, the Euclidean distance will be large.	

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[18] Two actors are structurally equivalent if they have identical ties to and from all other actors in the network. Because the structural equivalence requirement of perfectly identical ties seldom occurs in real social data, analysts typically relax this criterion by seeking to identify subsets of "approximately structurally equivalent" actors.

4.2	Correlation coefficient	The Pearson product-moment correlation coefficient computed on both the rows and columns of the sociomatrix	"Correlation" between two actors	If two actors are structurally equivalent, the correlation coefficient will be 1. The range is [-1,1]	As Euclidean distance increases, correlation coefficient will approach 0

Table 2: Telecommunications Network Measures

#	Measure	Formal Definition	Interpretation (usage)	Relationship with other measures	Impacts on Information Organizations
1	Network topology[19]				
1.1	network diameter	the length of the longest shortest path in the network	the scale of the **network**		responsiveness
1.2	expansion	the number of nodes that can be reached in a specified number of hops from a node	the scale of a **network**		responsiveness
1.3	edge connectivity	the smallest number of edges (links) whose removal disconnects a connected graph[20]	The bigger this number , the more robust the **network** is		robustness, reliability
1.4	vertex connectivity	the smallest number of vertices (nodes) whose removal disconnects a connected graph	The bigger this number , the more robust the **network** is		robustness, reliability
1.5	clustering coefficient	the ratio of the actual number of links connecting all neighbors of a node over the total possible numbers of links connecting them	the density of connections in the environment of a specific **node**		robustness, flexibility
1.6	resilience	the average number of links that needs to be removed to half split[21] a fixed-radius ball	measure the robust of a **network**		robustness

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[19] based on graph metrics.

[20] There is a path from any point to any other point in the graph.

[21] split the set of nodes contained by the ball into two subsets with roughly equal numbers of nodes

		centered on a node			
1.7	Betweeness	the number of shortest paths between all possible pairs of nodes in a network that traverse a link (node)	the centrality of a certain **channel** (**node**)		
2	Path cost metric		**Channel** selection		flexibility
2.1	hop count	The number of network devices between the starting node and the destination node	The length of a **channel**	each junction point (router, gateway, etc.) adds processing *overhead*	timeliness
2.2	load	the number of packets buffered at intermediate nodes	The traffic load of a **node**		efficiency, responsiveness
2.3	power capacity	the total transmission power of all nodes along the route	The energy cost of individual **node**s		network topology, reliability
3	Output		the amount of **information** through **channel** or **node**		
3.1	Bandwidth	The amount of data that can be passed along a communications channel in a given period of time.	the amount of **information** through **channel**	a physical-level measure	efficiency, responsiveness
3.2	Throughput[22]	the amount of digital data per time unit that is delivered over a physical or logical link, or that is passing through a certain network node	the amount of data successfully transported by the network per unit time (**information** through **node**/**channel**)	positively related with *bandwidth* and *packet loss*	efficiency, responsiveness [23]
3.3	Goodput	the number of useful bits per unit of time forwarded by the network from a source to a destination, excluding protocol overhead and retransmitted data packets	the amount of useful information that is transferred per unit time (**information** through **node**/**channel**)	the application-level *throughput*; often lower than the throughput	efficiency
3.4	capacity[24]	The maximum throughput of a node or link	the maximum amount of **information** that can be reliably transmitted over a particular **channel** or	*throughput*	efficiency, responsiveness; constraint

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[22] **system throughput** or **aggregate throughput** is the sum of the data rates that are delivered to all terminals in a network

[23] throughput = amount of info/time to transfer it, not directly related with responsiveness which is in terms of time,

			node per unit time		
3.5	Utilization[25]	the ratio of achieved throughput over the capacity	How far the amount of **information** transferred from the upper bound of **node**/**channel**	*throughput, capacity*	efficiency
3.6	Arrival rate	The mean number of new calling units arriving at a service facility per unit time	the amount of **information** arrived per time unit	corresponding to *throughput* [26]	
4	Time			*throughput* and physical distance (e.g. *hop count*, *length of path*)	
4.1	Latency[27] (delay)	the time[28] between the initiation of an data transmission by a sender and the initial receipt of that transmission by a receiver	the time for the complete **information** to be transferred from the source to the destination (through **network**)		responsiveness
4.2	RTT (Round-trip time/round-trip delay)	the time required for a signal pulse or packet to travel from a specific source to a specific destination and back again	the time for the **information** unit to be transferred from the source to the destination (through **network**)		responsiveness
4.3	Flooding time	the minimum time needed to reach all other nodes from a source node over their respective shortest paths	the minimum time needed to inform all nodes in a **network**		responsiveness
5	Information format				efficiency reliability
5.1	protocol overhead	the number of non-application bytes (protocol and media framing) divided by the total number of bytes in the message	data for transferring purpose and does not contribute to the content of the **information**		reliability, efficiency
5.2	Maximum transmission unit (MTU)	the size of the largest packet that a given layer of a communications protocol can pass onwards	The size of the data the channel can handle (**information** through **channel**)	Higher MTU may lead to higher *throughput*, but also increase *latency*	Efficiency

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[24] a commonly used term: Channel capacity

[25] a commonly used term: Channel utilization

[26] also called "departure rate"

[27] the time from the source sending a packet to the destination receiving it (**one-way latency**); the one-way latency from source to destination plus the one-way latency from the destination back to the source (**round-trip latency**)

[28] excluding the time spent on processing information

5.3	Maximum Segment Size (MSS)	the largest amount of data that a computer or communications device can handle in a single, unfragmented piece	The size of the data the channel can handle (**information** through **channel**)	*Goodput*; *latency*; *MTU* (=MSS + header)	Efficiency
6	Traffic problem		information with node		reliability, adaptability
6.1	Packet Loss	the discarding of data packets in a network when a device (switch, router, etc.) is overloaded and cannot accept any incoming data at a given moment	the amount of **information** which fail to reach their destination when travelling across a **network**	bit errors, network congestion	Reliability
6.2	bandwidth-delay product	the product of a data link's capacity times its end-to-end delay (sometimes the data link's capacity times its round-trip time)	the amount of data that have been transmitted but not yet received at any given time; the amount of yet-unacknowledged data that the sender has to duplicate in a buffer memory in case the client requires it to re-transmit a garbled or lost packet	*bandwidth*, *delay* (l*atency*)	reliability