Cooperation and Coordination in Decentralized Communication Networks

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Abstract

Research has shown that decentralized networks and organizations perform better and have more satisfied members than centralized ones. Further, decentralized self-organizing networks are superior when solving complex problems. Despite mounting research in support of decentralized networks, the means of how to foster and maintain a decentralized, yet coordinated network remains a particular problem. The current line of research proposes and illustrates a flock theory, which models decentralized organizational communication. Grounded in literature from social networks, flock theory represents a model for the decentralized evolution of communicative networks. The flock model is extended to integrate roadmap based flocking, bipartite networks, and findings from small world networks research to create a theory of cooperation, coordination, and navigation within decentralized communication networks. Empirical illustrations of flock theory are conducted via a case study, providing initial support for the theory.

1. Introduction

Human interaction may be more like jazz improvisation than a classical symphony. It may not seem like this would impact organizational networks, but this analogy has a great deal of application. At the basic level, the comparison between the two forms of musical performance revolves around the structure, or pattern, of the interaction. Improvisational jazz allows the individuals flexibility of expression [1], and a symphony has highly centralized control providing little latitude of interpretation to the individual performers. The jazz group still has a base level of structure, such as what key and tempo the performance will be in, but there is substantial room for interpretation and flexibility of group direction.

The structure of interaction amongst individuals in organizations can have as much variation as musical performance; some are decentralized and open, providing employees more freedom to make decisions and pay close attention to each other. On the other hand, some organizations are highly centralized, with most decisions coming from higher levels of the hierarchy; individual employees are not able to participate in decision-making or communicate as freely with other employees. Further, there is a great deal of impact that the structural composition of the organization can have on the performance and satisfaction of the employees, and the organization as a whole [2] [3].

Social network analysis has been widely used in the study of organizational structures, and has provided fruitful findings, yet the majority of the research is limited to implications of methodological results regarding structure and related variables (e.g. performance). What is lacking from the literature is a theoretical base indicating the means by which the groups and organizations studied can foster and maintain a decentralized structure, and how communication networks are central to the maintenance of these structures. Further, there is little research that extends existing decentralization literature to research-focused organizations such as universities.

Monge & Contractor [4] provide the most exhaustive review of the theoretical approaches to communication networks to date, with the review having a tendency towards organizational implications, and they point out several shortcomings (p. xi-xiii); 1) little research published on communication and organizational networks is motivated by network theories, 2) the field doesn't have an overarching framework for integrating conceptual, theoretical, and empirical work, 3) few network studies utilize theories as the basis for formulating hypotheses, and those that do often use single theories, 4) studies rarely tap into multiple network levels, and 5) emergent system properties has not been integrated very far into the domain of network research. These problems, and related issues, are central to the purpose of this research. The current research discusses the impact that structural differences can have on organizational performance, specifically, the advantages of decentralized structures on employee performance, collaboration, and knowledge sharing.

The first section of this paper provides a review of the social network perspective and research on group

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and organizational decentralization, including foundational work and recent advances. Specifically, findings from Shaw [5] are specified and extended through research by Sparrowe et al [6] and Cummings and Cross [3]. The second section covers flock theory, provides contributing literature, and extends the flock theory model to roadmap based flocking. The third section proposes the bipartite small world model as a means for a social system roadmap, covers contributing literature, and applies the model to flock theory. A case study then applies and illustrates portions of the theory.

2. Social Networks and Decentralization

Social network perspectives focus on the structure of social systems and how the elements of a social system come together. From the network perspective, the social environment can be expressed as patters or regularities in relationships among interacting units, often called structure.

The form of network that will be utilized herein is a communication network, defined as the patterns of contact that are created by the flow of messages among communicators through time and space [4]. Communication network analysis identifies the communication structure, or flow. Relation ties (linkages) between actors (nodes) are channels for the transfer (flow) of either material or nonmaterial resources, or for an association between individuals. The ties that exist between the nodes can vary along several elements, including direction, reciprocity, and strength.

As discussed above, networks are systems of interacting units linked to one another with structure and pattern. One specific kind of network is a knowledge network (KN), or "distributed repositories of knowledge elements from a larger domain that are tied together by knowledge linkages within and between organizations" [4]. One interesting element of KN is that the links that bind the network together are the perceptions that the people have of the knowledge networks within which they are associated. Thus, being abreast of what the other individuals know is crucial for a knowledge network to be utilized.

Knowledge networks are bound to the health of organizations, as distributed knowledge allows for people to bring unique knowledge enabling a collective to accomplish complex tasks [4]. Further, knowledge networks represent complex communicative systems, and can foster self-organizing. The greater the knowledge becomes part of the network, the more people can pool together their knowledge and spin off new knowledge.

2.1 Decentralization and Effects on Performance and Satisfaction

Shaw [5] directly investigated the relationship between communication structure and group performance. Findings related to network structure and effects on group performance and satisfaction show that decentralized networks perform better and made fewer errors than centralized networks, especially with complex tasks. Further, decentralized groups were more active (i.e. sent more messages), and were more satisfied.

One of the essential explanatory tenets of network theory is that structure in social networks has the ability to either constrain or augment contact with important resources [7]. Sparrowe et al. [6] extends this research, as well as that done by Shaw [5] by researching group network structure and performance, and how informal relationships potentially hinder individual and group performance.

Work-related resources (e.g. task advice and strategic information) are exchanged through informal organizational networks, yet these networks also transmit social support and identity [6]. Specifically, Sparrowe and colleagues focus on the exchange of task advice and information via advice networks (the means by which individuals can exchange informational resources essential to task completion), and on obstructive relations via hindrance networks (relationships between coworkers who thwart task behaviors).

Centrality in the advice network was positively related to individual performance, and centrality in the hindrance network was negatively related to individual performance. Hindrance network density was negatively related to group performance, which points to the conclusion that uncooperative behaviors are just as closely related to performance as cooperative behaviors, further compounding the importance of satisfied group members.

Cummings & Cross [3] researched similar effects of the structural properties of work groups and their consequences for performance. Structural properties used were; (a) hierarchical structure, (b) Core-periphery structures, where a there is a cohesive core and a sparse, unconnected periphery, which can hinder the ability of the more peripheral individuals from offering valuable information, and (c) structural holes, which forces individuals in the network to navigate through actors that bridge structural holes.

Analyzing 122 work groups in working on complex, non-routine projects, Cummings and Cross found hierarchical and core-periphery structures to be negatively associated with group communication. Hierarchical structures were negatively related to group both manager- and member-rated group performance. Greater core-periphery structure was negatively related to the manager-rated performance of the group, and greater structural holes of the group leader were negatively related to both manager- and leader-rated group performance.

Research on the social structure of groups and organizations indicates that decentralized structures are superior regarding group performance and satisfaction. However, there is a lack of theory suggesting the means by which these groups can maintain this decentralized structure while still interacting in a cohesive manner. The following section covers flock theory, proposed as a means by which a group or network can have a decentralized structure while also allowing for a cohesive interaction.

3. Flock Theory

Combining the central concepts of emergence [8], jamming [9], the emergence of creativity [10], and autopoiesis [11] as explanatory processes, flock theory models the self-organizing principles of cooperative evolution in human interaction. The structure of the theory, based on the rules "template" that Reynolds [12] used to simulate a bird flock, is extended to include concepts based on social science research (e.g., leadership and centralization concerns). Reynolds derived three simple rules that can incorporate the vast complexity of a flock, and render an accurate rule-based simulation of its behavior. Rule 1 - Separation: avoid crowding local flockmates, Rule 2 - Alignment: match average heading with nearby flockmates, Rule 3 - Flock Centering: move to the average position of nearby flockmates. When the birds in the computer simulation (called *boids*) followed these rules they can avoid environmental objects as well as split of from, and rejoin, the flock.

Flock theory models decentralized human interaction, where the throng of collective action between flock (group) members exemplifies the self-organizing ability of individuals that, despite their complexity, can demonstrate cooperative evolution. The coordinating ability of birds [12] is viewed as an exemplar that is used to elucidate structure, while simultaneously establishing three mechanisms of interaction, presented below.

3.1. Structural Distance

Structural distance, based on Reynolds' [12] first rule - separation, captures the concept explained by Eisenberg [9] as the balance of autonomy and interdependence, the "close but not too close, far but not too far" element. Groups that foster excessive autonomy may dissolve and groups that foster too much interdependence may stifle creativity [13]. Organization is created by the shared repertoire of communicative behaviors; the members of a group need to maintain a level of cohesion that allows for individual input without sacrificing group acceptance of new information (be it an idea for a task group, or a new key in a musical interaction). A group can become to close and corrode the ability for the group to navigate and change direction when necessary.

The structural distance construct proposes that groups need to include members in decision making to allow for accountability and the avoidance of conformity. Yet, the group must also allow for freedom of expression to avoid self-censorship. Structural distance should also not get too distant, as in the core/periphery research on work groups [3] presented above, as maintaining the structural distance of the group will allow for a greater likelihood for collaboration.

3.2. Collaboration

If structural distance is to be maintained in evolutionary processes, then the direction of change (either topically or task oriented) and the rate of change need to be a cooperative function amongst the group, as in Reynolds' second rule – alignment. This relates to Sawyer's [10] concept of processual intersubjectivity, or the establishment of a constantly changing emergent shared understanding; where that which is currently being established, as well as future emergence of creativity, has to proceed within the frame being created by this emergent interaction. Thus, to have a shared understanding the group members must attempt to match both the direction (norms) and velocity (tempo) of the other members. Central to this construct is the creation and maintenance of a group culture, or the norms and tempo that allow group members to reach a mutual understanding of both their interaction direction and velocity.

Group members should reflect the direction that the group is moving, which could be a change of topical direction in a conversation, a novel idea in a brainstorming group, or a change of key in improvisational music. The purpose of direction matching is to allow the group to evolve in a collaborative manner, while maintaining the structural properties of the system via normative behavior.

3.3. Decentralization

If a leadership role is present, it must shift in a manner such that no one actor maintains leadership for too long, and that the group is led in a purposeful direction, which hinges largely on the differences between individual and group emergent leadership. It is extremely pertinent in the case of cross-functional teams, where each member of the group has embedded knowledge that cannot be obtained from any other group member. It is in this sense that the leadership shifts and the group must self-organize with purpose.

It is helpful to conceptualize a decentralized leadership as a "goose rule," where a goose flock must shift leadership in an effort to maximize energy decay. Energy decay can be related to groups in that a leader can exhaust their energy within the group, and the individual that has not led for the longest time has build up the most potential energy, and should then lead in one of the successive moves. This also guarantees the efficient use of intellectual capital, much like a brainstorming session. Findings presented earlier regarding the success of decentralized work groups support the use of decentralized structures.

Maturana and Varela [11] note the importance of structural coupling in terms of autopoietic systems, and this concept is applied to group leadership as self-organizing. Thus, the role of leader is indeed passed from one actor to another in such a manner that intersubjectivity exists in the transformation of leadership shift.

Flock theory, as presented above, expresses a model for decentralized group organization. However, the means by which the group communicates and maintains a cogent knowledge of group goals and status, i.e. global information, needs to be established. The following section covers a roadmap based coordination system, where there can be *local organization* and *global information*.

4. Roadmap based flocking

Given the potential problem of a fully bottom up organizations' maintenance of a common purpose and cohesion, the main issue then relates to the nature of group organization given a decentralized structure. Since research has shown that centralized groups and organizations inhibit performance, the solution lies in the ability for a decentralized group working on complex problems to maintain a cohesive idea of group purpose and direction. Research on flocking behavior and complex problem solving poses a "roadmap" solution. Contrary to Reynolds [12] flocking simulations, where global behavior can arise from local influence, the flocking behavior explained in this section exhibits both local and global influence via *communication*.

Bayazit, Lien, & Amato [14], researching flocking behavior in complex environments, have found that goal oriented tasks are completed by the flock with more success when the group has global information along with local organization. Reynolds' flocking methods do not perform very well if complex navigation is needed. A map, containing a network of representative feasible paths, can provide path-planning queries in the environment. An example of such roadmap-based navigation is when various scientific research groups cooperate as to not duplicate efforts. Whereas each unit may be only locally organized, the global coordination of a research roadmap will diminish the likelihood of unnecessary resource duplication (e.g. research similar to the distributed human genome project).

Bayazit and colleagues [14] investigated whether flocking models that use planning methods provided by roadmaps support more sophisticated group behaviors than purely locally organized flocking can allow. Two behaviors investigated will be discussed; 1) homing, where the goal is to move the entire flock from a starting point to a goal position, and 2) two kinds of exploring, covering and goal searching. Covering requires all flock members to explore the environment attempting to visit all points of the environment. Goal searching requires individual members to explore the environment searching for a specific goal that is know known a priori, then, once the goal is located, all of the flock members should move to the goal. It is important to note that after the goal is found, it is communicated to the other group members by modifying the roadmap, making the roadmap both a *coordination device* and a *communication mechanism*.

Computational experiments compared traditional flocking behaviors (i.e. Reynolds' boids) with roadmap-based techniques. For the homing behavior a flock of 40 individuals was given 30 seconds to reach a goal; the roadmap-based flock was able to get all 40 members to the goal, and the basic flock was only able to get 10 to the goal. Exploring behavior was tested on both traditional and roadmap flock, as well as an ideal behavior with complete knowledge of the search status at all times (i.e. *a priori* knowledge of the goal). Comparing results to ideal behavior allows for the extrapolation of comparing roadmap techniques with optimal performance, establishing a best case for simulation efficiency.

Results revealed that the ideal behavior was able to cover almost 91% of the environment in the first 30 seconds; the roadmap-based behavior took 90 seconds reach a similar coverage point of 91.6%, and the traditional (boid) flocking behavior was only able to cover just over 80%. The traditional behavior reached the 80% coverage slightly faster than the roadmap behavior due to its tendency to bounce around and discover easily accessible areas quickly.

Goal searching experiments revealed that individuals in the traditional flocking behavior were not able to reach the goal, and none of the individuals were able to discover the narrow passage out of the small region in which they started. Roadmap behaviors were very close to ideal behaviors, with the group reaching the goal only 5 seconds later. However, the roadmap behavior was able to get two individuals to the goal before any of the individuals in the ideal behavior.

In summary, these findings indicate that augmenting the locally organized flock model with the global knowledge of a roadmap results in more efficient goal achievement and exploration of new territory. Yet extrapolating these findings to human social systems requires explication of the means by which such systems can maintain the decentralized social structure, while simultaneously knowing what each other knows and where the group is going.

Recent research into a network phenomenon called the small world theory provides a useful vocabulary and construct to model the balance of decentralized structure and a centralized repository of knowledge. Small worlds suggest that any individual is potentially connected to any other individual, regardless of the size of the population. Thus, small worlds are potentially inherently decentralized. The following section covers related small world research and proposes a model that explains how social roadmap based flocking behavior can take place.

5. Bipartite small worlds

A small world can be explicated by a network that exhibits two properties; tendencies of local clustering, and short distances between nodes (individuals) such that any node could be reached in an average of only a few steps [15]. The tight clusters are groups of people in social networks that are associated with each other through redundant ties that allow for local clustering, also called strong ties or close ties. Yet, there are also a substantial amount of “weak” ties that we have in our networks; these are the connections that our close ties have with people that are not necessarily connected to, or have much in common, with us. Weak ties have been shown to offer a greater possibility for effective social coordination called “the strength of weak ties” [16]. So it is paradoxically the weaker ties that link people to each other and to novel resources that reside in other tight clusters within a network. Likewise, bridges between different tight clusters, represented by weak ties are catalyzed by accessibility to a large number of nodes.

The combination of tight clusters (strong ties), and the diameter of the network (quantified by the average shortest distance of links between two nodes) increasing logarithmically with the number of nodes, gives the network its small world [17]. The diameter of the network remaining small in relation to the addition of nodes allows the nodes in the network to be connected with only a few links, even if the network gets quite large. Thus, any person on the planet could be only a few links away from any other person by navigating their strong ties (local clustering) and utilizing the large number of weak ties associated with each strong tie (long range reachability).

There is a fundamental difference between the notion that a short path can connect any two people, and their ability to find that path [15]. Underscoring this issue is the difference between broadcast and directed searches. A broadcast search involves an individual activating every link in their network, telling everyone they know, in turn telling everyone they know, and on. Thus, if a short path exists the message will eventually navigate this path.

Directed searches involve the passing of a message one link at a time. A directed search is far more efficient than a broadcast search in terms of the number of messages sent, but far less efficient in finding the shortest path for that message to take. Thus the problem remains, how does an individual in a network find what they need in only a few links? The scale-free model [18] would require the use of a hub or connector to navigate to the target, but this solution still suffers from the vulnerability issue relating to hubs, and the difficulty of application to social networks. A potential answer, as it turns out, is concerned with the social lives of people and the identities they develop; specifically, the affiliation of people with their interests (i.e. a social roadmap), represented by affiliation networks.

In affiliation networks, or bipartite networks, two nodes can be thought of as affiliated if they participate in the same group or event [19]. Affiliation networks differ from single mode networks in several ways. Affiliation networks are dual-mode, or two-mode, networks where a set of actors and a set of events describe collections of actions instead of simple ties between pairs of actors. Connections among members of one of the modes are based upon the linkages formed via the second mode. Figure 1 shows a bipartite graph where the nodes A through K can be thought of as individuals in a network, and the nodes 1 through 4 as event they were present for. The lower example is a unipartite representation of the same network, in which two individuals are connected by an edge (line) if they were present for the same events.

Much of the importance in studying affiliation networks is the individuals’ membership in collectives, or social circles [20], which provide conditions for development of interpersonal connections. Individuals are brought together through joint participation in social events, and participation in more than one event establishes a linkage between the two events; thus overlapping group membership allowing for the transmission of information between groups. Therefore, this can be interpreted as either actors being linked by events, or as events linked by actors [19].

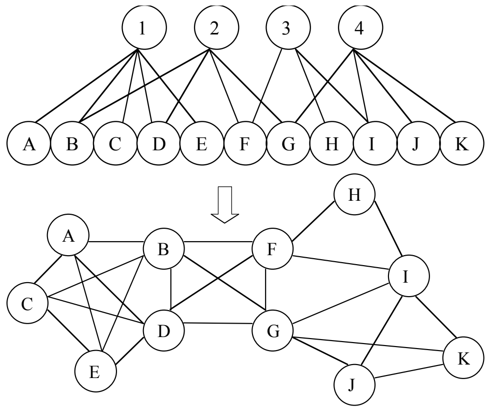

Figure 1. Bipartite network example

Watts [15] discussed the ability of multidimensional networks, where people have several dimensions to their identity – thus belonging to multiple groups, as to catalyzing an individual's navigation of their network. Yet, this proposition still requires the use of existing social networks for the acquisition of information on the reachability of a specific person. What is being proposed here is that searching for information contained by someone that is unknown is better done by searching via the content of what is needed allowing for a more directed navigation, much like in the roadmap based flocking experiments covered above.

5.1. Applications to flock theory

As covered in the previous section of this paper, the fundamental notions of flock theory allow for a network of individuals to: a) manage their social structure, b) collaborate (i.e. propose ideas and concepts that are supported by the network), and c) maintain decentralized, cooperative evolution.

5.1.1 Structure, mode one. The first element of flock theory proposes that for cooperation to occur, individuals in a social network should maintain a structure that is close-but-not-too-close (extreme cohesion) and far-but-not-too-far (breakdown of cohesive group). Notions of distance are central to the small-world construct, where local clusters are close, but no so close as to prohibit long range connections (as seen in clusters that are only strongly tied to themselves); and the random links to other clusters allow them to be far, but not too far (as is the case when short path lengths don't exist). The challenge then becomes the management of this distance.

The balance between randomness and order is crucial in small-world networks [15]; extrapolating this to the flock model asserts that the group of individuals needs to maintain a balance between autonomy and interdependence. Notions of distance based on a balance of randomness (autonomy), and order (interdependence), are discussed here as relating to the social structure mode of a bipartite (two-mode) network.

Individuals in a group (network) maintain a structure that allows for the close reachability of other members, while simultaneously allowing a certain amount of distance, or freedom, from the group structure. Like the bipartite network discussed in the previous section, this is done in relation to the second mode of the network – the roadmap.

5.1.2. Roadmap, mode two. The second element of flock theory posits that the collaboration requires the maintenance of distance, and is achieved through matching the "motion" of the other individuals. If distance is to be maintained in the evolutionary processes, than the direction of change (either topically or task oriented), and the rate of change needs to be a cooperative function amongst the group. However, without the roadmap, it is difficult for individuals to understand how far they are from each other, given that distance can be both physical as well as topical.

Outcomes of group interaction can often come from the peripheries of the network instead of from the center of a network (its leaders). Seemingly small events can result from group members' knowledge that seemingly random encounters can lead to a plethora of individual decisions, each made without a knowledge of a larger plan; yet, by some means aggregating into a momentous and unanticipated event [15]. In such cases the centralities of the individuals in the network would not reveal much about the outcome, as the center emerged as a result of the event itself. In the absence of a central actor, the attention then turns to the roadmap reveal where the hubs truly are.

If hubs form in the content mode of a bipartite network, than these content hubs allow the individuals to affiliate themselves with the topics and connect with each other in the physical mode via these affiliations. Further, the evolution of the system can be better understood as a shift of the hubs, either during a conversation or as a society at large (e.g. fads). Individuals remain clustered in their networks and navigate their distance based on their affiliation with the changing topic, or their position on the roadmap. Thus, supporting an idea in a brainstorming session or adding to a discussion in a newsgroup allows the other individuals to have a deeper understanding of how far they are from each other. It is important to note that if a topical direction change is to occur, the structure and connectivity of the network can have as much of an influence on the likelihood of adoption as the attraction of the idea itself [15], so the social distance mode is a precursor to the development of the content mode.

A group's reception of a directional change, or shifting of a topical hub, can be conceptualized as an information cascade, or the widespread reception of an idea. Information cascades occur when there is a specific network structure that allows for the breadth of the individuals in the network to be receptive to some specific information. It is in this sense that the combination of both modes of a bipartite network must be considered to understand how decentralization can exist amongst a set of individuals. The positing of an idea allows people to attach to it, either supporting it or not. If there is to be a cooperative evolution amongst the group, directional changes need to be initially supported (creating a new hub), as the individuals will be structurally linked to each other via new ideas and, at least initially, thus the distance is also maintained. Individuals in the network can maintain a close but not too close distance by connecting through the hubs, as well as supporting directional changes by allowing the new hubs to form and develop.

Even a fairly small group of individuals interacting can maintain a small-world structure, where everyone is only a few degrees of separation from each other, embodied by central hubs as well as local clustering. Yet there is still an important element to consider in this model - the avoidance of central hubs in the distance (social) mode of the network, as this can lead to network vulnerability. Hubs in the social mode can lead to dominant leaders as well, breaking down the cooperative element. Both of these issues can be resolved by shifting any presence of a leader (or at least having a decentralized decision process) in the social mode of the group, often as a result of individuals posing new ideas or topics.

5.1.3. Decentralized Evolution. The final element of flock theory posits that decentralization in crucial, and leadership amongst the group must shift in order to maintain an egalitarian, decentralized evolution. Instead of a network where a central leader directs network evolution, such as in the hub dominated scale-free small-world, important innovations can originate from the less central individuals [3] [5] [6]. The first two elements of flock theory, discussed above, unpack the means by which a network can have the content of the interaction predict the connections that form amongst people, yet there is still a possibility that all of the ideas presented will come from a small set of individuals (i.e. core/periphery), even in the case of an information cascade. To resolve this issue the group should attempt to shift the sources of input through the entire group so each individual can update the roadmap.

In small-world terms, the presence of a strong leader will have a similar effect as a hub, dominating the network and making the least connected nodes practically invisible. More importantly, the less connected nodes would have to go through the hub to access each other, which creates a situation that is far from egalitarian. Likewise, the group would be very susceptible to breakdown if the central hub were to possess an inability to solve a specific problem or distribute information properly. Much like a hierarchical organization, information brokering by individuals in upper levels of the hierarchy can often lead to information overload and a limited response to environmental ambiguity [21].

Ambiguity requires communication between people who have a variety of expertise and are thus mutually dependent, thus requiring distributed communication in an information-processing network [22]. A successful information-processing network will then distribute information to the roadmap with as much equality as possible, where a hub based scale-free model would require the central actors to unrealistically process an exponential amount of information. A robust information-processing network needs to distribute the workload of leadership as well as the redistribution of information; in line with the flock model, where the leadership shifts and information stems from the breadth of individuals. The research on decentralization presented earlier underscores the need for distributed leadership and information distribution.

A particularly fitting example of distributed leadership and information distribution is the trade off of specialization and cross-fertilization in academic research. The division of labor in research groups requires a large amount of information retrieval and sharing, yet the leadership is often distributed across several departments or campuses. Difficulties of distributed leadership are compounded by the frequency of the research group members often having an equal organizational rank (e.g. full professor, co-principal investigators). Research team members are often spread across different specializations, creating communication problems. Combining distributed leadership of equal stature with cross-fertilization creates many potential problems for research teams, problems that may be explained by the model proposed in this paper.

The first problem that may be experienced is that of leadership. Flock theory specifically models interactions where distributed leadership is a necessary component of collaboration. The second problem is that of coordination. The bipartite small world model offers a mechanism by which a distributed group can access information and coordinate activities by using a roadmap. Combining the theoretical utility of flock theory and bipartite small worlds allows for a view of academic research teams as highly coordinated and easily navigable. By each member of the team sharing their personal expertise as well as what they are currently working on, much like the roadmap flocks discussed earlier, would allow the entire group to know who is working on what, and how that work is helping the group relative to their goal. The human genome project [16] is a fine example of distributed coordination. Many equal ranking researchers were mapping an extremely complex genome by specifically sharing what parts they had solved, how those parts fit together, and what that contribution meant for the overall goal. The research groups used an information roadmap to see where they were relative to the other researchers, and were structurally collaborative and decentralized. In this sense, the research group is self-organizing by using communication to update the roadmap, and decentralized by allowing the roadmap to coordinate the groups.

Academic and research organizations are particularly fitting examples to elaborate the theory proposed in this paper, as the conventional problems of distributed leadership and informational coordination are beneficial to the groups in that the research often requires several different specializations. Academic organizations differ in several ways from traditional corporate organizations, as such, the next section illustrates several of the theoretical notions discussed this paper through a case study on 1,222 research groups in Europe.

6. Illustrating Example

The example discussed here illustrates portions of the theoretical model proposed above. Data utilized for the this study was collected in 1974 as part of a cooperative six-country project coordinated by the UNESCO secretariat, the International Comparative Study of the Organization and Performance of Research Units (ICSOPRU) [23]. First, background on the UNESCO data is provided along with rationale of fit with the theory. Next, related variables and expectations are explicated followed by statistical results. Finally, findings are presented followed by discussion and limitations of the example.

The ISCOPRU study provides for a multi-faceted evaluation of scientific productivity and effectiveness at the levels of the individual scientist and the research unit, as well as individual perceptions. The survey was conducted by six participating national research teams that administered standardized questionnaires to a sample of scientists drawn from nine major fields of science and technology, and represented about 200 research institutions in each of six countries [23]. The questionnaires incorporated a wide array of indicators for socio-psychological and sociological factors such as perceptions of influence patterns, organizational and group climate, structure, involvement, value of work, and the distribution of information. Although the data was collected in 1974, the structure of research organizations has not changed substantially.

A distinctive feature of the UNESCO study is that it was designed to specifically recognize purposeful systems and communication as the main organizing concept of research and development (R & D). Having the main goal of the initial research design focus on systemic organizing allows for several applications of the theory explicated in the previous sections to the data. Additionally, the theoretical and practical foundations of the approach adopted for the International Comparative Study derive from the theoretical perspectives of cybernetic modeling and systems analysis.

The combination of a) the initial research design of the UNESCO being centered on gaining information to allow for a structural, systems based approach; b) the foci on communication, creativity, and performance; and c) the potential difference between the relationship of the structural makeup and performance of a research organization as opposed to a traditional organization, provide an ample base to illustrate the theory proposed in this paper.

Surveys were collected by six participating national research teams that administered five standardized questionnaires to a sample of scientists chosen from nine major fields of science and technology, representing approximately 200 research units in each of the six countries and 1,222 research units in all. The questionnaires incorporate indicators such as satisfaction with the work environment, perceptions of influence patterns and inclusion of decision-making (leadership style), information on the professional experience, and extent of communication within and between research units.

Drawing from research findings on decentralization in traditional, corporate organizational settings, and extending the theoretical notions presented in flock theory and the bipartite model, hypotheses tested several relationships. One of the main constructs of flock theory, and parallel organizational research [5] [6], is that decentralization and cooperation are positively related to an atmosphere of supportiveness. Additionally, members of groups that require a high level of cooperation, an atmosphere of supportiveness, and influence over group decisions should have a greater perceived value of group performance.

Concerning the distribution of information in a decentralized group, as discussed in the roadmap based flocking section, groups that have an increased need for cooperation should have a greater amount of information on planning and research of the group.

Combining the roadmap model and the bipartite model indicates that an increased amount of information on planning and research should lead to increased involvement and influence in group decisions, general atmosphere and supportiveness, and an increased perception of group performance.

Finally, combining the multiple constructs of flock theory, the group members perceived value of the units work should be predicted by a combination of their involvement in research (structural distance), influence on decision-making within the research unit (decentralization), and general atmosphere and supportiveness (collaboration).

Although many significant positive relationships were found and all hypotheses were confirmed, the strongest relationship was between the degree of cooperation and the atmosphere of the unit ($r = .669$, $p < .001$). Based on the literature presented from corporate organizations, this is to be expected but was confirmatory of theory proposed that cooperation and a positive atmosphere go hand in hand.

Group atmosphere had moderate relationships with two other variables, the value of work ($r = .456$, $p < .001$) and the amount of information received ($r = .282$, $p < .001$). Likewise, cooperation had a moderate relationship with both the value of work ($r = .158$, $p < .001$) and amount of information received ($r = .151$, $p < .001$). These findings come together to paint a picture of groups that shows the more information group members have, the more they cooperate, and the more positive the atmosphere, the better they feel their work is. Relating these findings to the roadmap-based flocking and the bipartite model, it is expected that the more information that group members have and the more they cooperate, the better they will know where they are going as a group, and where to go for information within the group. Thus, more cooperation and a better product will be the outcome, as flock theory proposes.

Another interesting finding was the positive relationship between the amount of information received and the value of work ($r = .282$, $p < .001$), which suggests that the more that group members are included in what is happening within the organization, the better the outcome. Additionally, the more influence that the group members had over managerial decisions the better the value of the work was ($r = .201$, $p < .001$). This is a very important finding because it confirms the earlier research [3] [5] [6] and the portion of flock theory that proposes that the more decentralized the group structure and access to information, the better the group works.

Three variables were combined to represent the three core constructs of flock theory (structural distance, decentralization, and collaboration) and to test the main tangible outcome of flock theory, the quality and value of the work (e.g. of less tangible outcomes are satisfaction, egalitarianism, etc.). The perceived value of work should be predicted by a combination of the involvement in research, representing structural distance not being too distant, influence on decision-making within the research unit, representing decentralization, and the general atmosphere and supportiveness of the group, representing collaboration. The findings in support of this prediction, although moderate ($R^2_{adj} = .222$, $F_{3,\ 1149} = 109.2$, $p < .001$), suggest that the multiple constructs of flock theory do indeed work together to model the nature of quality work coming from a decentralized, collaborative group. The positive relationship of performance (as measured by the value of work) with several variables, including cooperation and influence over decision-making, highlights the association of decentralization and performance.

Earlier research on decentralization confirms that decentralized groups do indeed work better, but these findings extend that research to include a supportive atmosphere and the involvement in research. Further, atmosphere was the best predictor of the value of work, suggesting that it is may be particularly important to combine a cooperative, collaborative group atmosphere with decentralized group structure.

There are several limitations associated with this case study. The entire study utilized secondary level data, from which several limitations occur. First, there was no control or input possible regarding the construction of the instrument and selection of subjects. Second, there was no control over methods of data collection and data entry. Another limitation of this case study is the notion that it is only illustrating theoretical concepts discussed above instead of testing these concepts. Illustrating concepts helps in clarifying and discussing the theory, but empirical testing will be needed for theoretical validation. Finally, the complexity of the methods used on this case study is a limiting factor. More complex methods will be need in the future for empirical validation. Additionally, the possibility of the findings being caught in causal chains is a limitation that will also need to be addressed in future studies.

7. Conclusion

Research has presented us with findings leading to the conclusion that decentralization leads to more satisfied people and superior performance, and the current line if research proposes a model of how that decentralization can be fostered and utilized. One of the main motivations for this line of research is to promote more egalitarian organizations. Decentralized and self-organizing organizations can outperform centralized, autocratic ones. What the decentralized organizations capture is that every individual contains a massive amount of potential and the desire to contribute that potential, and to let him or her control that contribution. What the centralized, autocratic organizations don't enact is that motivation and contribution cannot be forced, bribed, or kicked out; motivation is internal. The way to turn the potential into kinetic is to allow people to collaborate, cooperate, and self-organize.

8. References

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