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Research Note

Opinion dynamics in command and control network with impact of informal organization

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Abstract. For social organizations, formal communication transmits goals, policies, and directions, while informal communications are supplement to the formal structure filling organizational gaps and maintaining the linkages. This communication model has been researched and named opinion dynamics for some years. However, the relations between formal and informal structures have not been fully revealed. To tackle this problem, this paper builds a hierarchical command and control (C2) organization network, introduces the basic opinion dynamics model and proposes the coupled network composed of formal and informal network. To study the communication impact of informal network on formal network, various numbers of groups and parameter settings (tolerance and influence) of the two networks are studied compared to standalone formal organizations. Experiment results show that informal organization has communication converging impact on opinion evolutions in military C2 network.

1. Introduction

Command and Control (C2) organizations are the exercise of authority and direction by a designated commander over assigned forces in the accomplishment of military missions [1]. Opinion exchange can reduce the uncertainty of decisions and gain consensus. Thus it is significant to study the opinion dynamics of C2 networks and propose better C2 structures for effective military operations [2]. Many opinion dynamics models have been developed so far. Opinion dynamics models can be classified as discrete or continuous, depending on the opinion values. Discrete models include Voter model [3], Sznajd model [4], Social Impact model [5], Axelrod Culture model [6], and Rumors model [7]. Deffuant model [8], Hegselman-Krause model [9], and CODA model [10] are continuous models. In C2 networks, if we interpret opinions in terms of agent's decisions, agents will take into account others' opinions by communications. Agent-based modeling is another popular approach to study social dynamics [11]. Bounded confidence and relative agreement models comprise an example of agent-based modeling [12]. In military C2 network, agents engage in interaction with connected agents whose opinion does not differ too much from their own opinions. The difference is called tolerance in [13], or threshold in [14].

Military C2 organization is formal and arranged in order strictly. Meanwhile, informal organization ubiquitously exists outside formal organization in various forms. Informal organization consists of a dynamic set of personal relationships, social networks, communities of common interest or motivation. Tended effectively, the informal organization complements the more explicit structures, plans, and processes of the formal organization: It can accelerate and enhance responses to unanticipated events, foster innovation, and enable people to solve problems that require collaboration

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across boundaries. Formal communications are those sanctioned by the organization itself and are oriented organizationally. Informal communications are socially sanctioned; they are oriented not to the organization itself, but to the individual members.

Ilie [15] observed that the direction of communication in military systems differentiates formal and informal patterns. The patterns are influenced by aspects like environment, education, training and experience. Opinion exchange is ubiquitous among different units of an organization, both in formal and informal structures [16]. Gulati and Puranam [17] developed a perspective on how inconsistencies between formal and informal organization can help create ambidextrous organizations. The authors argued that the informal organization can compensate for the formal organization by motivating a distinct but valuable form. Informal networks are important for promoting communication within and between organizations, which are viewed as structures that supplement, complement and add value to the formal organization [18]. It is certainly possible that an informal network inconsistent with the formal network may hamper the achievement of the espoused goals of the formal organization.

In describing "the network of social interactions that are not specified by the formal organization, but that develop on a personal level among workers in a company," Wells and Spinks [19] use the term "grapevine". They described the grapevine as humanly permanent, extremely fast, and highly accurate, providing qualified answers and usually bad news. It is important not to view an organization as based on either formal or informal network. Formal and informal networks exist concurrently and that two people who have a formal relation in one situation might have an informal relation in another. Furthermore, these same two people might have several formal and informal connections to each other, and the same informal network might be motivated by different factors over time.

Work in Song et al. [13,20] neglected the impact of informal network on the formal tree network. Informal network is the aggregate of norms, personal and professional connections through which work gets done and relationships are built among people. Thus, it is significant to study opinion dynamics in the military C2 network with the impact of informal network, i.e. opinion dynamics in a coupled network composed of formal and informal networks.

In summary, the main objective of this paper is to study the impact of informal organization on C2 system, which is built according to practical networks in Section 2. This realistic organization helps the study in this paper make more sense than virtually built networks. Section 3 proposes a coupled network in consideration of the impact of informal network and provides detailed simulation plans. Explicit results are also given in this section. Finally, conclusion is drawn in Section 4.

2. Opinion dynamics in military C2 network

2.1. Military C2 network model

Representative of typical formal network, an Armored Division C2 system instance is used to study opinion dynamics in hierarchical C2 network. The organization is basically a hierarchical tree structure (see Figure 1). The root node is Division, and its lower nodes are the Regiment, Battalion, Company and Platoon. The tree structure of Armored Division C2 system follows a 3-3 organization principle, which means each superior agent has 3 subordinate agents. For instance, one regiment agent has three battalion agents as his inferior agents. The organization is recursive until every platoon is composed of three tanks including a platoon tank and 2 wingmen. Totally,

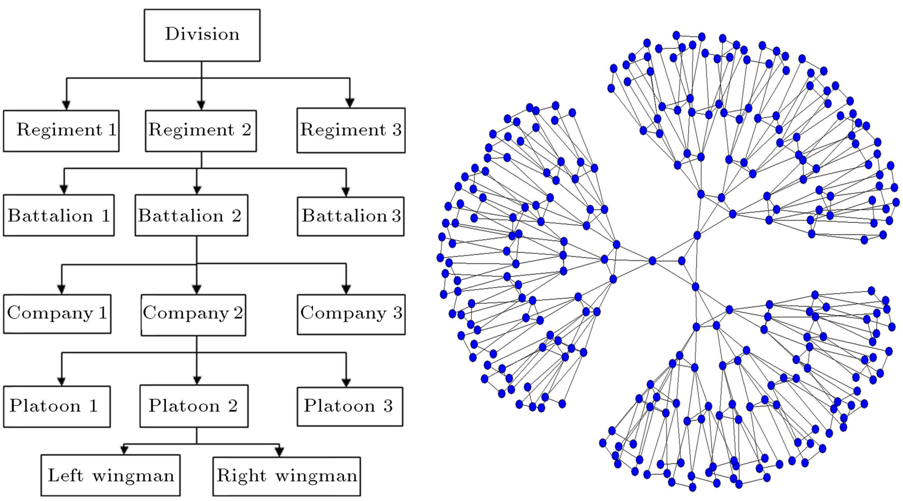

Figure 1. Hierarchical tree structure of an armored division.

this division C2 tree network is a set with 283 nodes (agents).

2.2. Opinion dynamics model in C2 network

Core aspects of opinion dynamics model are tolerance and influence. Suppose at time t, the opinion of agent i is $z_i(t) \in [0, 1]$. When agent i interacts with another agent j, it keeps its opinion fixed if the difference of their opinions is higher than the tolerance $d_{ij}(0 < d_{ij} < 1)$, i.e. $|z_i(t) - z_j(t)| > d_{ij}$, where d_{ij} is the tolerance of agent i to j. Otherwise, agent adjusts its opinion according to Eq. (1):

$$z_i(t+1) = z_i(t) - u^*_{ij}\left[z_i(t) - z_j(t)\right], \tag{1}$$

$z_i(t)$ and $z_j(t)$ denote the opinions of agents i and j at time t, u_{ij} is defined as influence of agent j on agent i. The larger tolerance means that the node can compromise with more different opinions, and the larger influence gives the node more opportunities for opinion adjustment in communications. Based on Eq. (1), we can get the general algorithm equation for each agent i in every communication round, which is as follows:

$$z_i(t+1) = z_i(t) - u^*_{ij}\left[\sum_j \left(z_i(t) - z_j(t)\right)\right] / N(j), \tag{2}$$

where, $N(j)$ means the number of agent j that meets the interaction conditions (agent i and agent j are connected and $|z_i(t) - z_j(t)| < d_{ij}$).

3. Opinion dynamics with impact of informal network

Informal organization refers to the emergent patterns of individual behavior, and interactions among individuals, as well as the norms, values, and beliefs that underlie such behaviors and interactions. Normally, informal network is not completely independent of formal C2 network. Based on the 283 C2 nodes in the Armored Division, our exampled informal network is primarily embodied in the links between each node (i.e., network structure) and established parameters (i.e., tolerance and influence of each C2 node) in the process of opinion evolutions.

3.1. Coupled network model composed of formal and informal network

Formal network and informal network co-exist and interact in realistic situations. Thus, in our experiments, informal network is made up of the same 283 nodes from the formal C2 network. However, nodes in informal network are fully connected instead of tree structure because agents are regarded as neighbors in the same group or community. Informal network may be divided into several groups uniformly based on a certain rule, and each node in its own group can only communicate with its neighbor in the same group. This communication outside the formal C2 network is regarded as informal communication, which may exert an impact on formal opinion dynamics. dynamics.

In our experiment, when informal networks are divided according to nodes' similar initial opinion values, we call it *type A*. This type of grouping indicates that initial opinions represent their common beliefs to some extent, and C2 nodes are inclined to get together with homogeneous peers such as classmates, comrades in arms, countrymen, etc. And we name it type B when nodes are randomly clustered as informal groups. This type of grouping reflects random and unpredictable factors in the formation of community.

Meanwhile, following these two types, informal network can then be uniformly divided into several groups. For instance, the informal network is to be uniformly divided into 2 groups with type A. Firstly, we set the floating initial opinion value, i.e., the uncertainty of C2 nodes, from 0 to 1. Then some nodes, whose opinion values are between 0 and 0.5 will be classified into Group 1, and nodes with an opinion value between 0.5 and 1 will be classified into Group 2. Both groups hold approximately 141 members. No matter what grouping type we use, the whole 283 nodes can be divided into several groups. Taking an 8-group informal network as an example, as Figure 2 shows, 8 different colors mark 8 different groups.

There are a few influence patterns of informal network on formal network. Influence pattern is the combination and implement sequence of formal communication and informal communication. We propose 3 influence patterns as Table 1 presents. No matter the communications is formal or informal, either mode cannot affect the other in one complete communication round. The influence pattern we propose is reasonable in actual circumstances. Taking pattern '2+1' as an example, informal network influences the formal opinion dynamics after 2 formal communication rounds. All nodes constitute an informal network and get into one informal communication process; of course, informal communications will change the opinion dynamics re-

Table 1. Notation and denotation of influence patterns.

Notation	Denotation of influence patterns
2+1	1 informal communication round after 2 formal communication rounds
1+1	1 informal communication round after 1 formal communication round
1+2	2 informal communication rounds after 1 formal communication round

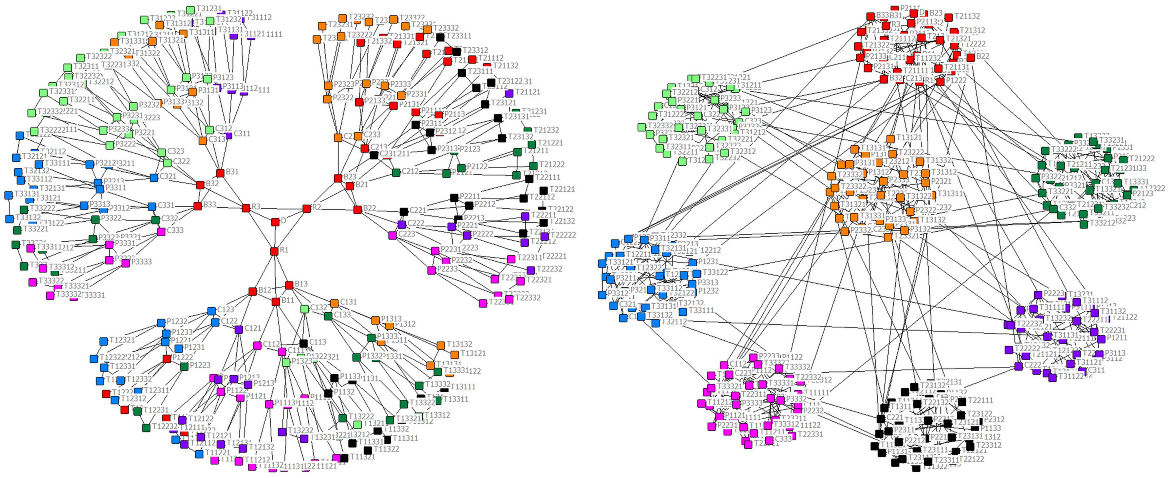

Figure 2. Informal network divided uniformly into 3 and 8 groups.

1. Generate initial opinion values between 0 and 1 by software for every node in the formal C2 network.
2. Modeling of informal network. In the situation of type A, the whole network is divided uniformly into several groups (illustrated in Figure 2) according to the initial opinion values. In the situation of type B, the whole network is divided in a stochastic way, which is not related to initial opinion values. Then model the informal network based on the given number of groups or clusters.
3. Setup tolerance and influence for every C2 node in formal and informal networks.
4. Calculate and update all the agents' opinion values based on 3 influence patterns (patterns '2+1', '1+1' and '1+2'). Afterwards, the next formal round is conducted until required communication rounds are accomplished.
5. Analyze the statistical results of opinion evolutions in one testing coupled network with fixed tolerance and influence.

Algorithm 1. Simulation algorithm for opinion dynamics in coupled network composed of formal and informal network

Table 2. Parameter settings of test groups 1 and 2.

Number	Tolerance of formal network	Influence of formal network	Tolerance of informal network	Influence of informal network
1	0.5	0.5	0.5	0.5
2	0.2	0.5	0.2	0.5

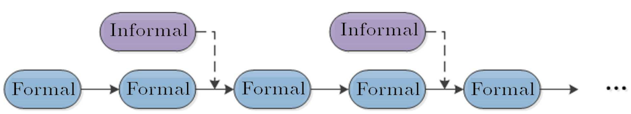

Figure 3. Illustration of pattern '2+1'.

sulting from formal communications to some extent. Illustration of pattern '2+1' is presented in Figure 3.

3.2. Simulation algorithm and experiments

In order to study the impact of informal networks on opinion dynamics of formal C2 organizations, comparison tests are carried out based on different parameter configuring of tolerance and influence shown in Table 2.

In the two group tests, opinion dynamics are simulated in the form of coexisting formal and informal network. Simulation algorithm for stand-alone formal network case is comparably easy to conduct according to Eqs. (1) and (2). Simulation algorithm for coupled case (with impact of informal network) is shown in Algorithm 1.

For all the simulation experiments, a few important statistical indexes are considered to evaluate the structure impact on opinion dynamics: *number of rounds to fixed opinions, number of opinion clusters and relative size of the largest opinion cluster.* Initial opinion values between 0 and 1, generated by software, are distributed uniformly. In order to analyze the data without slightly different opinions, we assume that nodes whose opinion differences are smaller than 0.001 belong to the same opinion cluster and the simulations are calculated in sufficient long time steps until the opinions are stable. This final step is referred to the number of rounds to fixed opinions.

Suppose the number of nodes in the network is N_0, and the number of rounds to fixed opinion of agent i is R_i, then the number of rounds to fixed opinions $R = \max\{R_1, R_2, ..., R_i, ..., R_{N_o}\}$. Number of opinion clusters in one opinion evolution is the number of different opinion clusters after the whole network reaches a steady state, i.e. each node's opinion value remains fixed. When the whole network reaches the steady state, the opinion cluster, which has the most nodes, is called the largest opinion cluster. Suppose the number of nodes in the largest opinion cluster is N_1, then the relative size of the largest opinion cluster is N_1/N_0 (N_0 is the total number of nodes in the formal C2 network).

3.3. Analyses of opinion dynamics in the coupled network

Results of opinion dynamics without the impact of informal network (formal case) are presented in Table 3, and we can observe visual opinion evolutions in Figure 4.

From Figure 4 and Table 3, we can observe that larger tolerance yields slower convergence speed. But the opinions in Test 1 can reach consensus after 2627 formal communication rounds. Although the number of rounds to fixed opinions in Test 2 is 335, the number of opinion clusters is up to 103. It is obvious that opinion dynamic in Test 1 is convergent and result in Test 2 is emanative. It is worth noting that all these results are calculated in formal communication without the impact of informal network.

At this point, we conduct simulations for coupled case, i.e. opinion dynamics in a coupled network composed of formal network and informal network. All the required parameters are already given in Table 2.

The result of number of rounds to fixed opinions

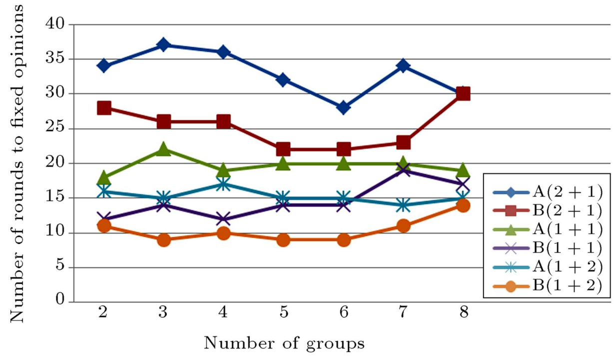

Figure 5. Number of rounds to fixed opinion in test 1 (coupled case).

is presented in Figure 5. The icon beside the chart represents the type of grouping and influence pattern. For example, $A(2 + 1)$ indicates that the informal network is divided into several groups according to the opinion values, and the influence pattern is '2+1'. It is observed that opinions get convergent faster by random grouping, so it means that grouping based on the initial opinions may reduce the diffusion of different opinions and result in a larger convergence time. On the other hand, we can find that pattern '1+2' is better than patterns '1+1' and '2+1' at accelerating the convergence. That is to say, frequent informal communication is beneficial to the convergence of opinions.

From Figure 6, we can draw almost the same conclusion that randomly grouped informal network is better at promoting opinions to fixed and stable, although the opinions cannot get convergent finally.

The results of the other indexes (number of opinion clusters, relative size of the largest cluster), in Test 1, are not presented, because all the opinions

Table 3. Results of opinion dynamics (formal case) in tests 1 and 2.

Number of test	Number of rounds to fixed opinions	Number of opinion clusters	Relative size of the largest opinion cluster
1	2627	1	1
2	335	103	0.135

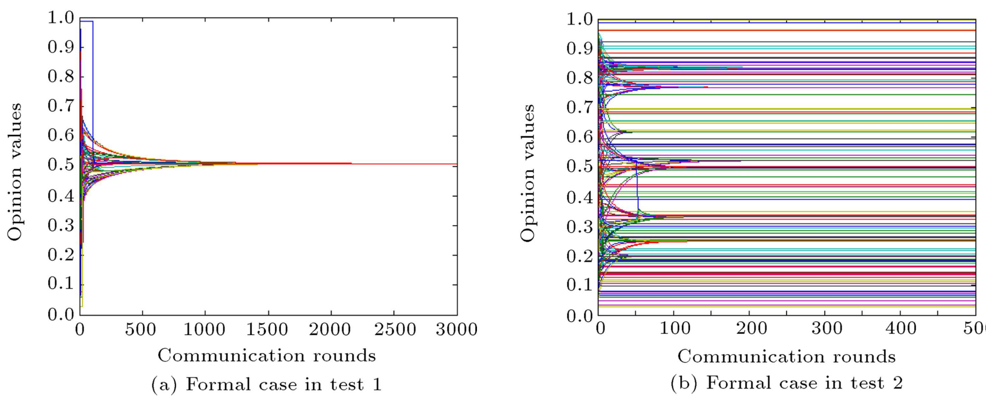

Figure 4. Opinion evolutions of formal communications in tests 1 and 2.

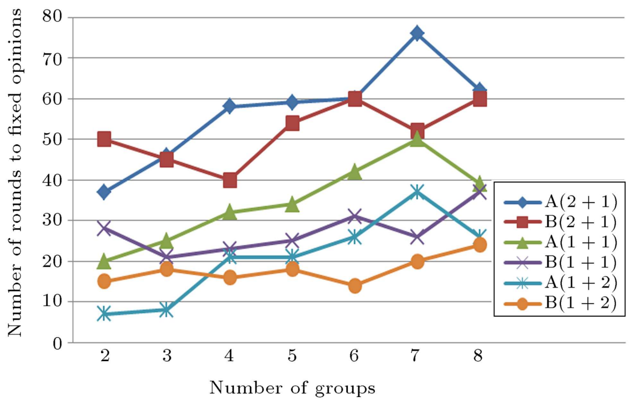

Figure 6. Number of rounds to fixed opinion in test 2 (coupled case).

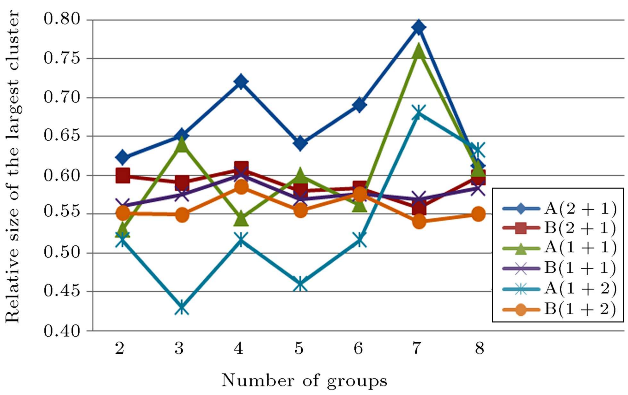

Figure 7. Relative size of the largest cluster in test 1 (coupled case).

converge finally. All the indexes in every situation are 1.

Moreover, Figure 7 shows the relative size of the largest cluster varying with different number of groups, type of grouping, and influence pattern. From Figure 7, we can find that this index is more stable when the informal network is divided randomly (type B). When the informal network is grouped based on similar opinion values, the index may be better, but the tendency varying with number of groups is unstable. When the informal network is divided randomly, the index is almost invariant with the number of groups.

One more opinion evolution experiment of Test 2 is presented in Figure 8. Here, the informal network is divided into 7 groups according to types A and B separately, and the influence pattern is '1+2'. The opinion evolutions can further prove our conclusions drawn above, i.e. randomly grouped informal network has better performance in the tendency to opinion convergence than similar opinion grouped informal network.

4. Conclusion

Based on a practical military organization, C2 network is built and the coupled networks of opinion dynamics are proposed and studied. Informal networks in our experiments are grouped randomly or based on similar initial opinion values. Results show that random grouping is better in facilitating the convergence or stabilization of opinions, and influence pattern also affects the result of opinion evolutions. As C2 is a typically formal and strictly hierarchical system which often has tree structure network, the discovered result is to some extent applicable to other hierarchically formal organizations.

In the future, more works need to be investigated in this field of study. For example, since this paper assumes that informal network affects the opinion evolutions of formal network with linear plus effect, it is worth studying how complex coordination and coexistence between formal and informal network take place.

Acknowledgment

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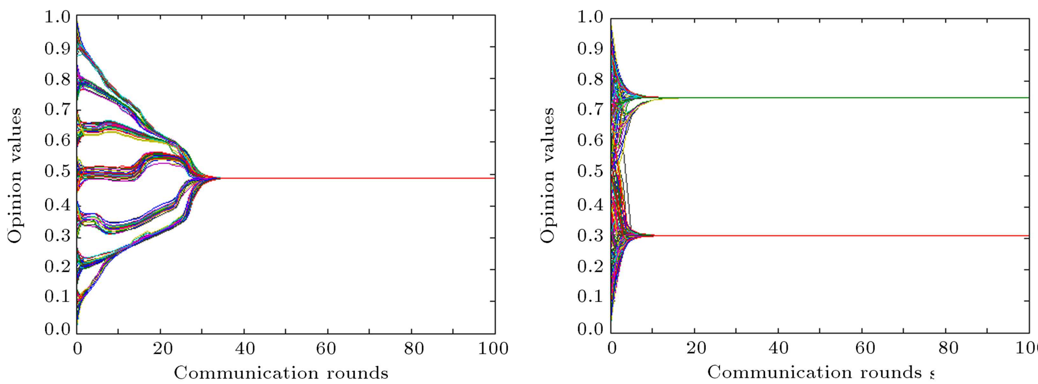

(a) Type A (b) Type B

Figure 8. Opinion evolutions (7 groups, pattern '1+2').

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Biographies

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