



Measuring group leadership in networks based on Shapley value

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Received: 1 November 2022 / Revised: 21 December 2022 / Accepted: 20 January 2023 / Published online: 12 February 2023
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Abstract

Measuring group leadership in social networks is a nontrivial task from a methodological viewpoint. The development of modern computational methods for evaluating group leadership is rooted in the analysis of network centralities. While computational methods for assessing the centralities of individual (i.e., single) nodes in networks have been well established, the methodological apparatus for computing group centralities has been much less developed. In the research domain of quantitative methods, this situation leads to the search for interdisciplinary solutions in which game theory currently plays a dominant role. This study analyzed two computational methods to measure group leadership in networks. Both are based on the game-theoretical concept of the Shapley value (SV). Based on the illustrative networks, the given research shows and discusses the strengths and weaknesses of the approaches. In short, the key finding of the study is that there is no “free lunch” method to measure group leadership, which means that each specific network requires an individual approach for choosing the most appropriate model.

Keywords Group leadership · Shapley value · Game theory · Network coalitions

1 Introduction

The analysis of group leadership in social networks from a computational viewpoint is driven by the need to understand the benefits of the collaboration of agents for effective group decision-making (GDM) (Zhou et al. 2018) and leadership formation (Weymes 2010). Due to the high complexity of socioeconomic environments, the expert-based analysis of the knowledge, expertise, and skills of agents working in groups frequently stays hidden from managers due to an insufficient level of knowledge about the topological position of agents in social networks (Patel et al. 2012; Murray and Moses 2005; Hossain and Wu 2009).

In GDM problems, the absence of a clear understanding of how group formation affects the distribution of leadership (i.e., influential power) in organizations (Hoyt et al. 2003) may lead to deceptive conclusions about the potential hidden behind the collaboration of agents acting as one unit (i.e., node in a network). In practice, this lack of understanding frequently leads to demotivation for information processing

(Scholten et al. 2007), a decreasing ability to find consensus in GDM problems (Alonso et al. 2010), and even failure in collective decision-making (Bahrami et al. 2012). According to Scholten et al. (2007) to actively cooperate in solving problems and making high-impact decisions, “group members need to engage in deep and systematic processing of information—only then will they uncover the hidden profile, unfreeze their initial and erroneous preferences, and achieve high quality decisions” (p. 540).

Research in the field of management shows that GDM directly affects the formation of leadership in organizations and, as a result, the quality of management decisions (Black et al. 2019). On the one hand, more individuals participating in decision-making are advantageous since each person contributes unique information or expertise to the group, as well as diverse viewpoints on the situation. On the other hand, groups often have more power of influence (i.e., higher leadership positions) than individuals in social networks. People with opposing viewpoints are often not listened to and are even ignored, which leads to the realization of ideas of only influential groups. The formation of groups in social networks can have both pros and cons in terms of individual and collective benefits in the context of organizational effectiveness (Paunova 2015).

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Although understanding individual and collective task performance in organizations are of particular research interest from the standpoint of disciplines such as social psychology (Lamm and Trommsdorff 1973) and leadership and management (Paunova 2015), the purpose of this study is not to analyze the advantages and disadvantages of group formation itself or the effectiveness of GDM on the functioning of social networks. Instead, this paper focuses on the computational aspects of the topological analysis of group leadership in social networks. The main goal is to understand how grouping initially separately functioning network agents into one group (i.e., topologically one single node) leads to a redistribution of leadership in a social network from a computational viewpoint. The research is motivated by the need for interdisciplinary research, with a special emphasis on the game-theoretic approach (Narayanam and Narahari 2011; Easley and Kleinberg 2010). In contrast to classic centrality-based analysis of leadership positions in networks (Newman 2018), combining social network analysis with game-theoretic methods offers an advantage in obtaining a more accurate quantitative analysis of the leadership positions of both initially individual nodes and nodes obtained as a result of grouping. In this article, we do not aim to cover different types of games from a game theory point of view but focus in particular on the concept of Shapley value, which shows promising results in taking into account the synergy that can arise between agents acting in groups (Aadithya et al. 2010; Flores et al. 2014, 2016; Michalak et al. 2013). The game-theoretic SV concept (Roth 1988) for obtaining joint gains from agents' interrelations in cooperative games (Peleg and Sudhölter 2007) is of particular interest in the given research due to its well-established mathematical framework and flexible adaptability for social network leadership analysis (Gładysz et al. 2019).

More specifically, the given study represents a comparative analysis of the two SV-based approaches to analyzing leadership positions in social networks. The first approach is based on the classical interpretation of SV for deriving agents' payoffs in cooperative games (Flores et al. 2014). The second approach is a computational approach of the SV concept adapted to the analysis of the leadership positions of agents in networks (Aadithya et al. 2010). Shapley Group value is used as a valuation of group performance as it is proposed in Flores et al. (2014) and Aadithya et al. (2010), but the specific use and therefore the consequences depend on selection of the game. Flores et al. (2014) are focused on the game with transferable utility (TU-game), which they emphasize in their paper by saying that "since we will restrict to the case of TU games in the sequel, we will refer to them simply as games" (p. 3). The Aadithya et al. (2010) approach is based on using SV of a very specific game as a centrality measure. All players (i.e., nodes) of the coalition S are grouped into a single player who acts as a representative

of the coalition S , and the game defined over the graph (i.e., network) is given by the number of nodes in the graph at most one degree away from nodes in the coalition S .

2 Comparative analysis

The analysis of centralities reflects leadership formation in networks. Measuring centralities for groups (i.e., coalitions) in networks is as important as it is for individual nodes. For example, to measure "how central is the engineering department in the informal influence network of the company" (Everett and Borgatti 2010, p.181), it is necessary to calculate the group centrality. Most centralities for groups and classes are based on classical structural measures (Everett and Borgatti 2010). However, the development of well-formalized mechanisms to calculate centralities for network coalitions based on the game-theoretical concept of SV can make a significant contribution to the domain of social network analysis.

In the present research, we analyze two computational methods for measuring group leadership (i.e., group centrality in networks) developed by Aadithya et al. (2010) and (Flores et al. 2014). Although both approaches are based on game theory, the main difference between them is how the formation of a group does affect the current social relations among their members. Flores et al. (2014) approach, which leans more toward the classical interpretation of the generalized SV (Marichal et al. 2007), is based on the assumption that it is not necessary for players to agree to act jointly knowing each other. Instead, the authors suggest "the existence of an external agent, the decision maker, that is able to coordinate the actions of the members of the group" (Flores et al. 2014, p.2). However, the decision to form a group and act as a group can emerge from the group members as well when the deliberate action to accomplish some tasks in the group requires full interconnection (Flores et al. 2016).

Aadithya et al. (2010), who use an algorithmic interpretation of SV, gravitate toward a game-theoretic analysis of relationships between players based on their network centralities and geodesic distances from each other. Based on the topological characteristics of the players' positions in the network, Aadithya's approach does not primarily focus on whether players have any social intentions to form groups or not, as it takes into account structural changes in the network. If the players decide to work in a group (based on their mutual decision or under the influence of an external agent), Aadithya's approach will take into account structural changes in the network, analyzing SV based on the topological characteristics of interconnections between players.

It is important to emphasize that the analysis of both computational approaches is done at the micro-level, which means that the focus is on illustrating and understanding

how each of the approaches calculates group centrality at the single nodes' level. This helps to see in great detail the Shapley-based redistribution of influential power (i.e., centrality values) before and after grouping individual nodes. It is important to emphasize that since both computational approaches are well-established and validated mechanisms for network SV-based leadership analysis, this study is not intended to test or illustrate these approaches in networks larger than those used in this section. As mentioned above, the aim is to conduct a comparative analysis at the micro-level and discuss the advantages and disadvantages of both methods.

The functionality of computational methods is illustrated based on the topology of a mixed symmetrical network. Since this network structure combines the fundamental types of network architectures such as bus, star, and ring (Haddadi et al. 2008), the computational results presented in this paper encapsulate the mutual effect of the topological aspects of these network architectures on the distribution of influential power. Another aspect of the analysis performed is the way in which the individual nodes are combined, namely the grouping of nodes and merging into one node. Notably, there is a big difference in the computational results for grouping nodes and merging them (as showed later in the article). In terms of networks, grouping nodes imply that internal joint intra-group cooperation affects relations with out-of-group nodes in the network. For example, employees in an organizational network might be asked to collaborate on a project based on shared communication with other members of the organization outside of their intra-group relationship. Merging nodes imply the delegation of rights from all merging nodes to only one of them, or to one abstract node that inherits the relations of all merging nodes. For example, an employee may be asked to take over the duties of another one (due to illness, dismissal, etc.), which would mean merging the duties and work-related communications of two employees into one work unit (on a permanent or temporary basis).

An important feature of the analysis presented below is the division of the analysis of each approach into two cases. The first case demonstrates the calculation of centralities in a network where the grouped nodes were initially (i.e., before the grouping) connected to each other directly (i.e., not through intermediate nodes). Accordingly, the second case applies to networks in which the grouped nodes were initially (i.e., before the grouping) connected to each other indirectly (i.e., through intermediate nodes). This division into two cases is dictated by the difference in the computational results for the grouped nodes initially connected to each other directly or through intermediaries in the network.

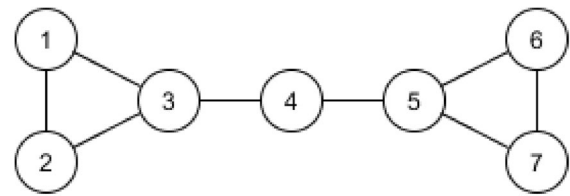


Fig. 1 Network with a mixed symmetric topology

Table 1 Initial SVs based on the first approach

Node	Shapley value
1	- 0.021
2	- 0.021
3	0.362
4	0.362
5	0.362
6	- 0.021
7	- 0.021

2.1 Group Leadership Measure: First Approach

The first approach analyzed in this study was developed by Flores et al. (2014). To measure group leadership in networks, the authors used the classical interpretation of SV, as presented in Eq. 1:

$$SV_i(v) = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|!(n - |S| - 1)!}{n!} (v(S \cup \{i\}) - v(S)), \quad (1)$$

where N is the set of n players, S is the coalition of players, and v is the characteristic function $2^N \rightarrow \mathbb{R}$; $v(\emptyset) = 0$.

Consider social network as an undirected graph $G(V,E)$ that reflects the connectivity game (Amer and Giménez 2004) with the following value function for the coalition (i.e., group) S:

$$v(S) = \begin{cases} 1, & \text{if } S \text{ connected in } E \text{ and } |S| > 1, \\ 0, & \text{otherwise,} \end{cases} \quad \text{for all } S \subseteq V.$$

The value of $v(S)$ is equal to one if there is a path between all nodes in S that contains more than one node. Otherwise, a zero value is assigned to $v(S)$.

Consider the graph with a mixed symmetric topology presented in Fig. 1.

Initially, individual SVs for all nodes were calculated based on $v(S)$ (see Table 1).

In Table 1, there are seven coalitions, where each coalition S contains only one node, and $v(\{1\}) = v(\{2\}) = \dots = v(\{7\}) = 0$. It is important to specify that it is possible to obtain a negative SV for the node or for the coalition of nodes. The “peripheral” nodes $i = 1, 2, 6, 7$ get $SV(i) = - 0.021$, and the

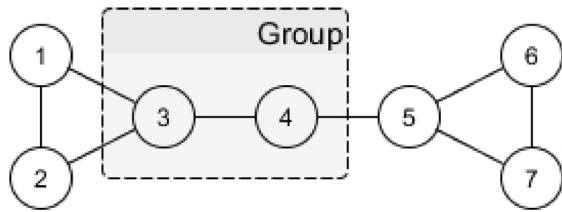


Fig. 2 Network with $S = \{3,4\}$

Table 2 First approach: SVs considering $S = \{3,4\}$

Node	Shapley value
1	- 0.033
2	- 0.033
{3,4}	0.667
5	0.467
6	- 0.033
7	- 0.033

more valuable nodes $i = 3,4,5$ get $SV(i) = 0.362$ due to their “centric” location.

2.1.1 Grouping directly connected nodes

Next, the directly connected Nodes 3 and 4 are grouped together to calculate the SV of $S = \{3,4\}$, which is illustrated in Fig. 2. For example, it could be a situation where two employees from the same department are assigned to work on a project in tandem with the subsequent submission of a joint report.

Based on Flores et al. (2014), we have $v(\{3,4\}) = 1$ because 3 and 4 are connected forming a path and $|S| = 2$. Table 2 presents the overall results.

According to Table 2, the “peripheral” nodes 1, 2, 6, and 7 lost their leadership positions in terms of SV values. Based on the grouping of nodes 3 and 4, both node 5 and the group {3,4} strengthened their leadership positions. The strengthening of the leadership position of node 5 is based on its «hub»-status. More specifically, it is directly linked to the group {3,4}, which has the highest SV and two “peripheral” nodes. Group {3,4} has the strongest leadership position since its members merged their powers as “centric” players in the network. In accordance with the efficiency requirement for the SV concept (Hart 1989), the total SV is equal to one. When {3,4} and 5 get an SV gain, the initially “peripheral” nodes lose their positions.

Next, consider the option where directly connected nodes 3 and 4 are merged into one node, as represented in Fig. 3.

In this case, for the merged node “3–4,” the value of $v(\{“3–4”\})$ is equal to zero, because $l\{“3–4”\} = 1$. Table 3 presents the resulting SVs.

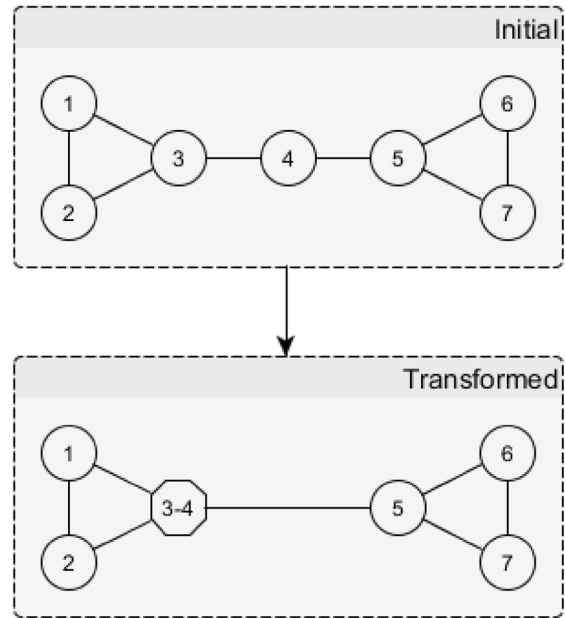


Fig. 3 Nodes 3 and 4 are merged

Table 3 SVs: Nodes 3 and 4 are merged

Node	Shapley value
1	0.0
2	0.0
“3–4”	0.5
5	0.5
6	0.0
7	0.0

According to the results given in Table 3, the merged node “3–4” and node 5 have equal SVs because of the symmetric nature of the transformed graph. The “peripheral” nodes get equal SVs: $SV(\{1\}) = SV(\{2\}) = SV(\{6\}) = SV(\{7\}) = 0$. In the transformed graph, the number of nodes decreased from seven to six. Consequently, the number of links connecting nodes 1 and 2 with nodes 6 and 7 is reduced. Accordingly, their SVs improved from negative to zero values.

Notably, according to the results represented in Tables 2–3, the value of $SV(\{3,4\})$ is greater than the value of $SV(\{“3–4”\})$. In other words, considering directly connected nodes 3 and 4 as one group improve the joint leadership much more than merging nodes 3 and 4 into one node.

2.1.2 Grouping indirectly connected nodes

The indirectly connected nodes 3 and 5 are grouped together to calculate the SV of $S = \{3,5\}$, which is illustrated in Fig. 4.

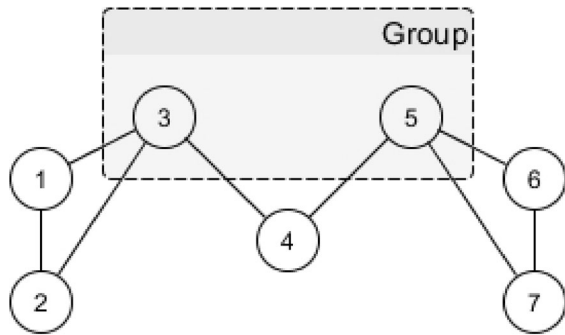


Fig. 4 Network with $S = \{3,5\}$

Table 4 SVs considering $S = \{3,5\}$

Node	Shapley value
1	0.017
2	0.017
{3,5}	0.467
4	0.467
6	0.017
7	0.017

According to Flores et al. (2014), group {3,5} is considered as a set of two disconnected nodes, but not as one entity in terms of connectivity. Since S is disconnected, the value of $v(\{3,5\})$ is equal to zero. Table 4 presents the resulting SVs.

According to Table 4, all nodes have positive SVs. Compared to the case with $S = \{3,4\}$ (see Fig. 2), the “peripheral” nodes $i = 1, 2, 6, 7$ get stronger leadership positions with $SV(i) = 0.017$. Basically, this stronger position can be explained by the direct connection of nodes 1 and 2 with nodes 6 and 7 through the “hub” represented by group {3,5} (see Fig. 4). It is not required for the left-side “peripheral” nodes to go through an additional node (i.e., node 4) to get to the right-side “peripheral” nodes and vice versa. Even though node 4 lost its “hub” status, it gets the same leadership position as $S = \{3,5\}$ (i.e., $SV(4) = SV(\{3,5\})$) due to its direct connections to all sub-nodes of the “hub” {3,5}.

Next, consider the case when indirectly connected nodes 3 and 5 are merged into one node “3–5” as represented in Fig. 5. For example, this could be a situation where two employees from different departments (but with the same project manager) are assigned to work on a project in tandem and then, submit a joint report.

Table 5 presents the resulting SVs.

The merged node “3–5” becomes the only centric node in the network by connecting to all others directly. Sequentially, it becomes the most powerful with the highest SV. Node 4 gets the lowest SV (i.e., $SV(4) = 0$), losing its leadership position. Now, node 4 has become the most “peripheral” in the

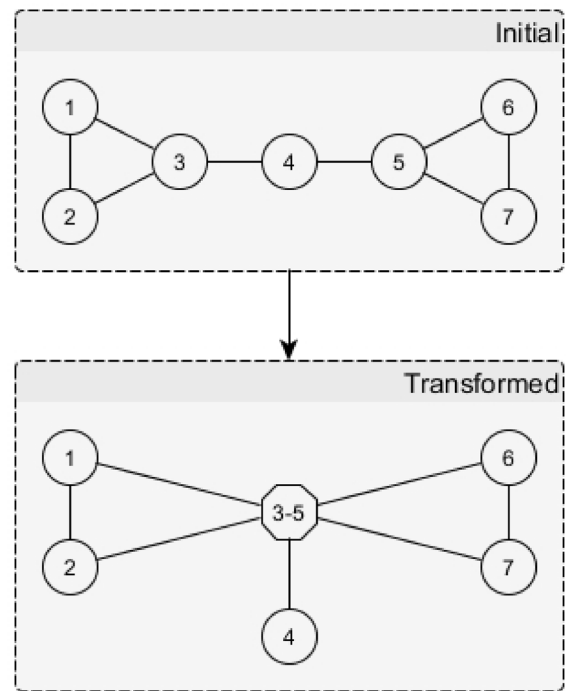


Fig. 5 Nodes 3 and 5 are merged

Table 5 First approach: Nodes 3 and 5 are merged

Node	Shapley value
1	0.05
2	0.05
“3–5”	0.80
4	0.00
6	0.05
7	0.05

transformed network. Compared to node 4, nodes 1, 2, 6, and 7 improve their leadership positions, as they are not only connected to the “hub” but also maintain local connections with each other. Specifically, links (1,2) and (6,7) are parts of the cliques with the merged nodes “3–5”: 1–2–“3–5” and 6–7–“3–5,” respectively.

2.2 Group Leadership Measure: Second Approach

The second approach has a dual nature. It encapsulates concepts from the domains of game theory and the theory of algorithms. The approach for single nodes was developed by (Michalak et al. 2013):

Table 6 Initial SVs based on the second approach

Node	Degree	Shapley value
1	2	0.917
2	2	0.917
3	3	1.250
4	2	0.833
5	3	1.250
6	2	0.917
7	2	0.917

Table 7 Second approach: SVs considering $S = \{3,4\}$

Node	Degree	Shapley value
1	2	0.917
2	2	0.917
{3,4}	3	1.167
5	3	1.167
6	2	0.917
7	2	0.917

SV-COMPUTING:

Input: Unweighted graph $G(V,E)$

Output: SVs of all nodes in $V(G)$

For each $v \in V(G)$ do

```

    ShapleyValue [v] =  $\frac{1}{1+\text{deg}_G(v)}$ ;
    For each  $u \in N_G(v)$  do
        ShapleyValue [v] +=  $\frac{1}{1+\text{deg}_G(u)}$ ;
    end
end

```

end

return ShapleyValue

In this study, the SV-COMPUTING approach was used to measure group SVs substituting single nodes with nodes' coalitions.

Consider the initial network with a mixed symmetric topology shown in Fig. 1. Initially, individual SVs are calculated for seven coalitions, represented by single nodes: $S_1 = \{1\}, S_2 = \{2\}, \dots, S_7 = \{7\}$ (see Table 6).

In accordance with degree centralities, nodes 3 and 5 get the highest SVs. The "peripheral" nodes $i = 1, 2, 6, 7$ get $SV(i) = 0.917$, which is higher than $SV(4) = 0.833$. Although node 4 has a "hub" status, nodes 1, 2, and 3 form one clique, and nodes 5, 6, and 7 form another clique. This involvement in a clique structure helps them to retain higher SVs higher than that of "hub" node 4.

2.2.1 Grouping directly connected nodes

First, the directly connected nodes 3 and 4 are grouped to calculate the SV of $S = \{3,4\}$ (see Fig. 2). Table 7 presents the results.

Since $\text{deg}\{3,4\} = \text{deg}\{5\} = 3$, their SVs are equal: $SV(\{3,4\}) = SV(\{5\})$.

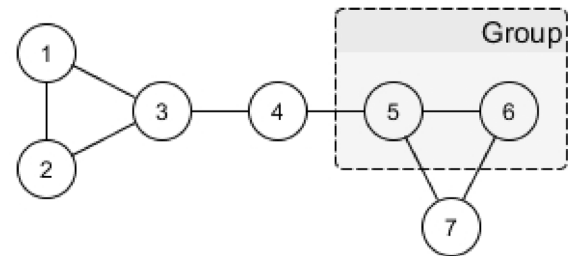


Fig. 6 Grouped nodes 5 and 6 with $\text{deg}(\{5,6\}) = 3$

Table 8 SVs considering $\text{deg}(\{5,6\}) = 3$

Node	Degree	Shapley value
1	2	0.917
2	2	0.917
3	3	1.250
4	2	0.833
{5,6}	3	1.250
7	2	0.833

Note that if nodes 3 and 4 are merged into node "3-4," as shown in Fig. 3, then, we get the same results for the second approach, as shown in Table 3. In terms of Aadithya's approach (Aadithya et al. 2010), group {3,4} and merged node "3-4" have the same degree centrality, which gives an equal effect in terms of SV-based leadership.

The issue of how to calculate SV-based group centrality in the second approach occurs for coalitions with the directly connected nodes when some node, which is out of S, is directly connected to more than one node in S. There are two cases. The first case involves counting all links between the internal (i.e., S-nodes) and external (i.e., nodes out of S) nodes. The second case is based on the idea of merging all connections of an external node with S-nodes into one link.

Consider the coalition $S = \{5,6\}$, where node 7 is connected to both nodes 5 and 6. There are two cases:

Case 1: Consider $\text{deg}(\{5,6\}) = 3$ and $\text{deg}(7) = 2$, which is illustrated in Fig. 6.

Table 8 presents the resulting SVs.

Case 2: $\text{deg}(\{5,6\}) = 2$ and $\text{deg}(7) = 1$, as depicted in Fig. 7.

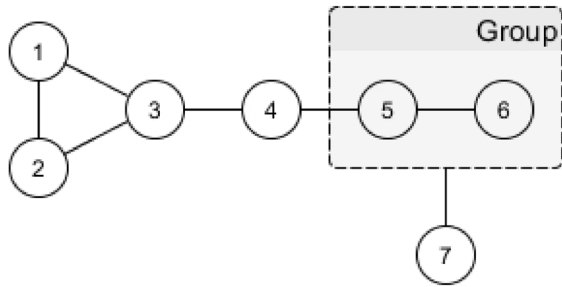


Fig. 7 Grouped nodes 5 and 6 with $\text{deg}(\{5,6\})=2$

Table 9 SVs considering $\text{deg}(\{5,6\})=2$

Node	Degree	Shapley value
1	2	0.917
2	2	0.917
3	3	1.250
4	2	0.917
{5,6}	2	1.167
7	1	0.833

Table 9 presents the resulting SVs.

Case 1 is based on the double counting of links between node 7 and group {5,6}, where we consider the relations of all coalition members with an “external world.” Case 2 is based on counting of only one link between node 7 and group {5,6}, which acts as one holistic entity. The leadership position of the coalition {5,6} in Case 1 is stronger than that in Case 2 because of the greater number of relations with the “external world.” Merging nodes 5 and 6 into one node “5–6” will get the same results as for the group {5,6}, as shown in Table 9.

2.2.2 Grouping indirectly connected nodes

Indirectly connected nodes 3 and 5 are grouped to calculate the SV of $S = \{3,5\}$ in the initial graph represented in Fig. 1. The main issue in this case is how to calculate the degree of the coalition $S = \{3,5\}$ and of node 4, which is directly connected to both nodes in S . Again, consider two cases:

Case 1: Consider $\text{deg}(\{3,5\})=6$ and $\text{deg}(4)=2$, as presented in Fig. 8.

Table 10 presents the resulting SVs.

Case 2: $\text{deg}(\{3,5\})=5$ and $\text{deg}(4)=1$, as presented in Fig. 9.

Table 11 presents the resulting SVs.

In Case 1, $\text{SV}(\{3,5\})$ is higher than in Case 2, mainly because of the difference in degree centralities of the coalition {3,5}. Now, consider the case when indirectly connected nodes 3 and 5 are merged into one node “3–5,” as shown in Fig. 5. Table 12 presents the resulting SVs.

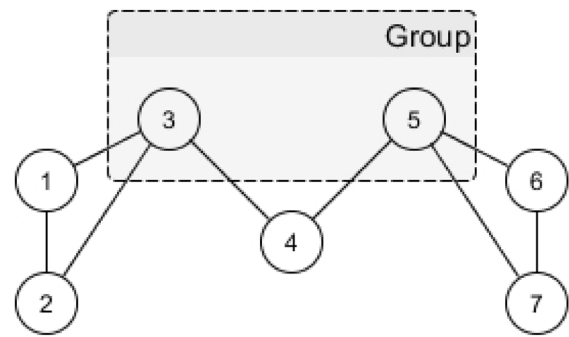


Fig. 8 Grouped nodes 3 and 5 with $\text{deg}(\{3,5\})=6$

Table 10 SVs considering $\text{deg}(\{3,5\})=6$

Node	Degree	Shapley value
1	2	0.810
2	2	0.810
{3,5}	6	2.143
4	2	0.619
6	2	0.810
7	2	0.810

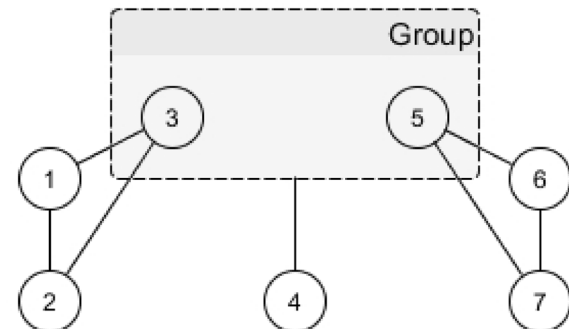


Fig. 9 Grouped nodes 3 and 5 with $\text{deg}(\{3,5\})=5$

Table 11 SVs considering $\text{deg}(\{3,5\})=5$

Node	Degree	Shapley value
1	2	0.833
2	2	0.833
{3,5}	5	2.000
4	1	0.667
6	2	0.833
7	2	0.833

The final results presented in Table 12 are equal to the results shown in Table 11 because group {3,5} has the same degree centrality as the merged node “3–5” as well as all other corresponding nodes from Figs. 5 and 9.

Table 12 Second approach: Nodes 3 and 5 are merged

Node	Degree	Shapley value
1	2	0.833
2	2	0.833
“3–5”	5	2.000
4	1	0.667
6	2	0.833
7	2	0.833

3 Conclusion and Discussion

This study analyzed two representative approaches to measuring group leadership using the SV concept from cooperative game theory. The computational results show that there is no unique approach for measuring group leadership in social networks based on the SV. Each method has its advantages and limitations.

Flores’s approach (Flores et al. 2014) to measuring group leadership employs the concept of classical SVs based on the objective function for coalitions (i.e., network groups). The given method shows the comprehensive distribution of a total surplus among all nodes within a network. However, based on the computational nature of the classical SV, this method has an exponential time complexity that limits its use to networks with a small number of nodes (Maleki et al. 2014). This limitation is critically important for group leadership analysis because most real-world networks have a large-scale essence. Another limitation of this method is that the SV can obtain negative values, which complicates the interpretation of how the resulting SVs reflect the real agents’ leadership in networks.

The advantage of the Aadithya’s approach (Aadithya et al. 2010), which was adapted for the group SV calculation, is its polynomial running time, which makes this method applicable to large-scale networks. This method also has a theoretical game background, which offers more opportunities for further research in the domain of group leadership analysis due to the well-developed analytical apparatus of game theory. However, as the given research indicated, one of the issues of this method is how to compute the degree centralities of coalitions and nodes that are simultaneously connected to more than one member of some specific coalition. We described two scenarios to overcome this uncertainty, but the final choice has to be made by decision makers who work with practical social networks, as each particular case requires individual analysis and testing.

In summary, the approaches by Aadithya et al. (2010) and (Flores et al. 2014) both have advantages and disadvantages. The analysis shows that there is no single solution in terms of methods for measuring group leadership in networks. The choice of a method for calculating group centralities in

social networks should be carried out individually in each specific case.

Author contributions Dr. Ivan Belik wrote the main manuscript. The author has no competing interests to declare that are relevant to the content of this article.

Funding Open access funding provided by Norwegian School Of Economics.

Declarations

Conflict of interest The author has no competing interests to declare that are relevant to the content of this article.

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References

- Aadithya KV, Ravindran B, Michalak TP, Jennings NR (2010) Efficient computation of the shapley value for centrality in networks. In: International workshop on internet and network economics, 6484 LNCS:1–13. Springer, Berlin. https://doi.org/10.1007/978-3-642-17572-5_1.
- Alonso S, Herrera-Viedma E, Chiclana F, Herrera F (2010) A web based consensus support system for group decision making problems and incomplete preferences. *Inf Sci* 180(23):4477–4495. <https://doi.org/10.1016/J.INFSCI.2010.08.005>
- Amer R, Giménez JM (2004) A connectivity game for graphs. *Math Methods Oper Res* 60(3):453–470. <https://doi.org/10.1007/S001860400356>
- Bahrami B, Olsen K, Bang D, Roepstorff A, Rees G, Frith C (2012) What failure in collective decision-making tells us about metacognition. *Philos Trans R Soc B Biol Sci* 367(1594):1350–1365. <https://doi.org/10.1098/RSTB.2011.0420>
- Black S, Bright DS, Gardner DG, Hartmann E, Lambert J, Leduc LM, Leopold J et al (2019) Organizational behavior. OpenStax, Houston
- Easley D, Kleinberg J (2010) Networks, crowds, and markets: reasoning about a highly connected world, vol 81. Cambridge University Press. <https://doi.org/10.1017/CBO9780511761942>.
- Everett MG, Borgatti SP (2010) The centrality of groups and classes. *J Math Soc* 23(3):181–201. <https://doi.org/10.1080/0022250X.1999.9990219>
- Flores R, Molina E, Tejada J (2016) Assessment of groups in a network organization based on the shapley group value. *Decis Support Syst* 83:97–105. <https://doi.org/10.1016/J.DSS.2016.01.001>
- Flores R, Molina E, Tejada J (2014) The shapley group value. <https://doi.org/10.48550/arxiv.1412.5429>.
- Gładysz B, Mercik J, Ramsey D (2019) A fuzzy approach to some shapley value problems in group decision making. *Handbook of*

- the shapley value, pp 483–513. <https://doi.org/10.1201/9781351241410>
- Haddadi H, Rio M, Iannaccone G, Moore A, Mortier R (2008) Network topologies: inference, modeling, and generation. *IEEE Commun Surv Tutor* 10(2):48–69. <https://doi.org/10.1109/COMST.2008.4564479>
- Hart S (1989) Shapley value. *Game Theory*. https://doi.org/10.1007/978-1-349-20181-5_25
- Hossain L, Wu A (2009) Communications network centrality correlates to organisational coordination. *Int J Project Manage* 27(8):795–811. <https://doi.org/10.1016/J.IJPROMAN.2009.02.003>
- Hoyt CL, Murphy SE, Halverson SK, Watson CB (2003) Group leadership: efficacy and effectiveness. *Group Dyn* 7(4):259–274. <https://doi.org/10.1037/1089-2699.7.4.259>
- Lamm H, Trommsdorff G (1973) Group versus individual performance on tasks requiring ideational proficiency (brainstorming): a review. *Eur J Soc Psychol* 3(4):361–388. <https://doi.org/10.1002/EJSP.2420030402>
- Maleki S, Tran-Thanh L, Hines G, Talal R, Rogers A (2014) Bounding the estimation error of sampling-based shapley value approximation. <https://doi.org/10.48550/arXiv.1306.4265>
- Marichal JL, Kojadinovic I, Fujimoto K (2007) Axiomatic characterizations of generalized values. *Discret Appl Math* 155(1):26–43. <https://doi.org/10.1016/J.DAM.2006.05.002>
- Michalak TP, Aadithya KV, Szczepanski PL, Ravindran B, Jennings NR (2013) Efficient computation of the shapley value for game-theoretic network centrality. *J Artif Intell Res*. <https://doi.org/10.1613/jair.3806>
- Murray P, Moses M (2005) The centrality of teams in the organisational learning process. *Manag Decis* 43(9):1186–1202. <https://doi.org/10.1108/00251740510626263/FULL/PDF>
- Narayanan R, Narahari Y (2011) A shapley value-based approach to discover influential nodes in social networks. *IEEE Trans Autom Sci Eng* 8(1):130–147. <https://doi.org/10.1109/TASE.2010.2052042>
- Newman M (2018) *Networks*, 2nd edn. Oxford University Press, Oxford
- Patel H, Pettitt M, Wilson JR (2012) Factors of collaborative working: a framework for a collaboration model. *Appl Ergon* 43(1):1–26. <https://doi.org/10.1016/J.APERGO.2011.04.009>
- Paunova M (2015) The emergence of individual and collective leadership in task groups: a matter of achievement and ascription. *Leadersh Q* 26(6):935–957. <https://doi.org/10.1016/J.LEAQUA.2015.10.002>
- Peleg B, Sudhölter P (2007) *Introduction to the theory of cooperative games*. Springer Science & Business Media
- Roth AE (1988) *The Shapley value: essays in honor of Lloyd S.* Cambridge University Press, Shapley
- Scholten L, van Knippenberg D, Nijstad BA, De Dreu CKW (2007) Motivated information processing and group decision-making: effects of process accountability on information processing and decision quality. *J Exp Soc Psychol* 43(4):539–552. <https://doi.org/10.1016/J.JESP.2006.05.010>
- Weymes Ed (2010) Relationships not leadership sustain successful organisations. *J Chang Manag* 3(4):319–331. <https://doi.org/10.1080/1714023844>
- Zhou H, Ma X, Zhou L, Chen H, Ding W (2018) A novel approach to group decision-making with interval-valued intuitionistic fuzzy preference relations via shapley value. *Int J Fuzzy Syst* 20(4):1172–1187. <https://doi.org/10.1007/S40815-017-0412-0/FIGURES/6>

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