European Journal of Operational Research 229 (2013) 230–238

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Cooperative game theoretic centrality analysis of terrorist networks: The cases of Jemaah Islamiyah and Al Qaeda

R.H.A. Lindelauf[a,b], H.J.M. Hamers[b], B.G.M. Husslage[b,c,*]

[a] *Military Operational Art & Science, Netherlands Defense Academy, P.O. Box 90002, 4800 PA Breda, The Netherlands*
[b] *CentER and Department of Econometrics and Operations Research, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, The Netherlands*
[c] *Department of Mathematics, Fontys University of Applied Sciences, P.O. Box 90900, 5000 GA Tilburg, The Netherlands*

ARTICLE INFO

Article history:
Received 25 June 2012
Accepted 16 February 2013
Available online 27 February 2013

Keywords:
Terrorism
Network analysis
Centrality
Cooperative game theory

ABSTRACT

The identification of key players in a terrorist organization aids in preventing attacks, the efficient allocation of surveillance measures, and the destabilization of the corresponding network. In this paper, we introduce a game theoretic approach to identify key players in terrorist networks. In particular we use the Shapley value as a measure of importance in cooperative games that are specifically designed to reflect the context of the terrorist organization at hand. The advantage of this approach is that both the structure of the terrorist network, which usually reflects a communication and interaction structure, as well as non-network features, i.e., individual based parameters such as financial means or bomb building skills, can be taken into account. The application of our methodology to the analysis results in rankings of the terrorists in the network. We illustrate our methodology through two case studies: Jemaah Islamiyah's Bali bombing and Al Qaedas 9/11 attack, which lead to new insights in the operational networks responsible for these attacks.

1. Introduction

The identification of the key players in a terrorist organization is a major problem in targeting top terrorists in counterterrorism practice. Currently key leader engagement is often based on qualitative theories, such as those of charismatic leadership (Jordan, 2009). With the huge increase in digital information gathering, intelligence and law enforcement agencies possess large volumes of raw, heterogeneous, often incomplete and inaccurate data on terrorist networks (McAndrew, 1999; Sparrow, 1991). The use of sophisticated quantitative modeling techniques and procedures to clean and make sense of these data is however limited (Xu and Chen, 2005). One of the quantitative methodologies that is often applied to find the proverbial needle in the haystack in general social networks is *social network analysis* (Wasserman and Faust, 1994). This methodology has also been applied to terrorist networks, see, e.g., Koschade (2006). A common feature of social network analysis is that it only uses the structure of networks. In this paper we introduce a methodology that additionally incorporates information available on a terrorist group in the analysis of the social network underlying the terrorist group. We show that quantitative modeling by means of cooperative game theoretic centrality measures enables the incorporation of such additional information.

Several researchers have shown how complex data on criminal organizations can be analyzed using the *network perspective*, e.g., Sparrow (1991), Peterson (1994) and Klerks (2001). Quantitative analyses of terrorist networks include Carley et al. (2003), Farley (2003) and Lindelauf et al. (2009).

The strength of social network analysis lies in the fact that one takes interrelationships into account when analyzing a group of people (Ressler, 2006). Centrality analyses can be applied to find the most important person in a social network. Clearly, 'most important' depends on the context of the problem under consideration. Hence, many different centrality measures have been proposed. A centrality analysis leads to a ranking of individuals that are active in the social network. Three of the most well-known centrality measures arising in social network analysis are degree centrality, betweenness centrality and closeness centrality (cf. Wasserman and Faust, 1994). In this paper we refer to these three centrality measures as *standard centrality*. Software implementation of standard centrality is found in, for example, Ucinet (Analytic Technologies, 2010). Furthermore, Analyst's Notebook (I2, 2010), a software package used worldwide by law enforcement and intelligence agencies, has recently included standard centrality in its latest update. Unfortunately, most, if not all, centrality measures currently in use in the intelligence and law enforcement domain focus specifically on the social network structure (that is, who

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* Corresponding author at: Department of Mathematics, Fontys University of Applied Sciences, P.O. Box 90900, 5000 GA Tilburg, The Netherlands. Tel.: +31 855070593.

E-mail address: b.husslage@fontys.nl (B.G.M. Husslage).

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http://dx.doi.org/10.1016/j.ejor.2013.02.032

interacts with whom), and do not incorporate other information often available. In the context of terrorist networks such additional information can be twofold: either information on individual terrorists, like financial means, bomb building skills, attendance of individuals to certain meetings, signs of radicalization or presence at a terrorist training camp, or information on relationships between terrorists, ranging from the frequency and duration of interaction between individuals to the quantities of weapons being transported. Standard centrality is not able to incorporate this kind of data.

In this paper we use cooperative game theory to develop rankings of individuals in terrorist networks based on both the structure of the terrorist network and additional information on the terrorists and their relationships. Cooperative game theory has been used in networks to investigate how power is allocated (cf. Jackson, 2008; Gomez et al., 2003). In this paper we apply cooperative game theory to terrorist networks, which include, in contrast to the networks considered by Jackson and Gomez et al. features that do not only depend on the network structure. Clearly, a terrorist organization can be considered as a social network as it consists of players working together to achieve a goal. A typical example would be a group of insurgents trying to carry out attacks with improvised explosive devices. To successfully launch such attacks several tasks have to be conducted: finances have to be arranged, the bomb material has to be acquired, the bomb has to be built and reconnaissance has to be conducted at the potential attack site. Hence, a terrorist group needs to consist of individuals capable of performing such tasks. Moreover, terrorist groups heavily rely on communication networks to accomplish acts of recruitment and planning (Tsvetovat and Carley, 2005). The structure of a terrorist network, however, differs significantly from a general social network (cf. Lindelauf et al., 2009, 2011). Similar to social networks, we want to determine the key players in terrorist networks. Using game theoretic centrality measures, rankings of players in such a terrorist network can be developed. Because game theoretic models are able to handle additional information by assigning values to coalitions, this approach provides more realistic models to identify key players in a terrorist network.

In this paper we show how cooperative game theory can aid in the identification of key players in a terrorist network. We introduce a weighted connectivity game that is able to take both the structure of the terrorist network as well as information about the individual terrorists into account. Applying a game theoretic centrality measure to the weighted connectivity game leads to a ranking of the players in the terrorist network. This allows for the optimal allocation of scarce observation resources and the destabilization of the terrorist network by the removal of the highest ranking members. To facilitate practical implementation of our methodology we present a general framework that includes three stages: construct the network, define the game theoretic model and analyze the rankings of players. We illustrate this framework through two practical cases: the Jemaah Islamiyah bombing in Bali and the 9/11 attack by Al Qaeda. The analyses of these cases with degree centrality, betweenness centrality and closeness centrality in concurrence with game theoretic connectivity centrality have led to some new results and insights. We therefore state that quantitative centrality analyses provide a valuable contribution to the identification of key players in terrorist networks and hence are useful in combating the violent and disrupting phenomenon called terrorism.

The paper is organized as follows. After recapitulating the basic standard centrality measures in Section 2 we introduce a general framework for game theoretic centrality analysis. We show how law enforcement and intelligence agencies can apply this framework to terrorist networks, in particular when additional information about the terrorist network is available. We also introduce the (weighted) connectivity game and a game theoretic centrality measure. In Section 3 we illustrate the practical use of centrality analyses in two case studies in which we compare the standard centrality measures to case study specific game theoretic centrality measures.

2. Game theoretic centrality

In this section we introduce a game theoretic centrality measure to determine the key player in a terrorist network. Cooperative game theory studies situations in which players can generate benefits by working together. In this view a terrorist organization also consists of individuals that form (opportunity) coalitions in order to achieve a certain goal, e.g., to carry out an attack.

First, however, we briefly recapitulate standard centrality. A (social) network can mathematically be represented by a graph $G = (N, E)$, where the node set N represents the set of persons in the network and the set of edges E consists of all relationships that exist between these persons. A relationship between person i and j is denoted by $ij \in E$.

The idea behind degree centrality (Proctor and Loomis, 1951) is that the more people one knows the more important one is. The *normalized degree centrality* of person i is expressed as the fraction of the network with which person i is directly related:

$$C_{\text{degree}}(i) = \frac{d(i)}{|N| - 1}, \tag{1}$$

where $d(i)$ represents the number of direct relations of person i and $|N|$ is the total number of persons in the network. Observe that $0 \leqslant C_{\text{degree}}(i) \leqslant 1$.

Betweenness centrality was first introduced by Freeman (1977). The idea is that a person is important when he enables the flow of information between other persons in the network. Betweenness centrality is measured by counting the number of shortest paths (i.e., a path that uses a minimal number of links) between two persons that pass through another person. Let s_{kj} denote the total number of shortest paths between person k and j and let s_{kij} denote the number of shortest paths between k and j that pass through person i. The *normalized betweenness centrality* of person i is then defined through

$$C_{\text{between}}(i) = \frac{2}{(|N|-1)(|N|-2)} \cdot \sum_{\substack{k,j \in N \setminus \{i\} \\ k<j}} \frac{s_{kij}}{s_{kj}}. \tag{2}$$

Again, it follows that $0 \leqslant C_{\text{between}}(i) \leqslant 1$.

Finally, closeness centrality quantifies the distance from a certain person to all other persons in the network. The *normalized closeness centrality* of person i is defined by

$$C_{\text{close}}(i) = \frac{|N| - 1}{\sum_{j \in N} l_{ij}}, \tag{3}$$

where l_{ij} denotes the shortest distance between person i and j. Again, observe that $0 \leqslant C_{\text{close}}(i) \leqslant 1$. Borgatti and Everett (2006) argue that the essence of closeness centrality is *time-until-arrival* of entities that flow through a network, whereas betweenness centrality measures the *frequency-of-arrival* of flows in a network.

Note that the actual standard centrality values are not important to us, only the resulting ordinal rankings of the persons involved are of interest. The following example illustrates the use of standard centrality.

2.1. Example: standard centrality measures

Consider the social network depicted in Fig. 1. The nodes represent seven persons, denoted by letters A to G, that are part of the