Estimating Vulnerabilities in Large Covert Networks

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Modeling and Simulation

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Abstract

Covert organizations, such as terrorist groups, have network structures that are distinct from those in typical hierarchical organizations; e.g., they are cellular and distributed. Reasoning about how to attack dynamic networked organizations, let alone figuring out how they are likely to evolve, change, and adapt is terribly difficult. In this paper, an approach to estimating vulnerabilities and the impact of eliminating those vulnerabilities in covert networks is presented. Key features of this work include: using detailed network data to supplement high level views of organizations to create a composite image, using network metrics for mult-mode, multi-plex data to characterize key actors and the network itself, and using multi-agent simulation to predict change in the composite network view over time. Uncertainty is handled by using two types of data to reduce uncertainty, running the model in a Monte-Carlo fashion to determine the robustness of the results, and examining the robustness of the results under adding and dropping nodes and edges in the underlying networks. This approach is illustrated by contrasting the differential predictions for al-Qa'ida and Hamas as the top leaders are removed.

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Covert organizations, such as terrorist groups, have network structures that are distinct from those in typical hierarchical organizations; e.g., they are cellular and distributed. Reasoning about how to attack dynamic networked organizations (Ronfelt and Arquilla, 2001), let alone figuring out how they are likely to evolve, change, and adapt is terribly difficult. Part of this difficulty stems from their covert nature.

Social network analysis employs sets of tools and theories developed to collect, analyze and explain the topology of networks formed by who talks to, works with, is connected to whom and the relevance of position in this network to individual and group outcomes. Clearly social networks can be applied to the study of covert networks (Sparrow, 1991). Many are stepping forward suggesting that to understand these networks we just need to "connect the dots" and then isolate the "key actors who are often defined in terms of their "centrality" in the network. To an extent, this is right. However, it belies the difficulty of "connecting the dots" in terms of mining vast quantities of information, pattern matching on agent characteristics for people who go under multiple aliases, and still ending up with information the may be intentionally misleading, inaccurate, out-of-date, and incomplete. Further, this belies the difficulty in "knowing" who the "network elite" are when you have at best only a sample of the network. Finally, and critically, this approach does not contend with the most pressing problem – the underlying network is dynamic. Just because you isolate a key actor or formal leader today does not mean that the network will be destabilized and unable to respond. Rather, it is possible, that isolating such an actor may have the same effect as cutting off the Hydra's head; many new key actors or leaders may emerge (Carley, Lee and Krackhardt, 2001) and they may be more prone to hostile activity than their predecessor.

To understand the dynamics of terrorist, and indeed any, network we need to understand the basic processes by which networks evolve. Moreover, we have to evaluate isolation strategies in the face of an evolving network and in the face of missing information. To ignore either the dynamics or the lack of information is liable to lead to erroneous, and possibly devastatingly wrong, policies. Taking in to account both the dynamics and the lack of information should engender a more cautious approach in which we can ask, "What are likely to be the effects of an action." This is critical if we are to reduce surprise in the field and enable planning of operations that takes in to account effects due to network dynamics.

In this paper, the limits of standard social network analysis as they relate to the extraction and analysis of covert networks are described, This is followed by a discussion of the types of "errors" that are likely to appear in relational data and the way that shapes the observed network Possible procedures for reducing such errors are then described. Then the impact of such errors on estimating key actors is then discussed. This is followed by a discussion of what happens when key actors are isolated. Then a series of studies, showing the impact of these types of missing information on locating vulnerabilities in different classes of networks will be provided. The results place the analysis of destabilization strategies in a risk framework allowing the analyst to estimate the chances that they are wrong.

1 AVAILABLE DATA

Available data exists in a variety of forms including, but not limited to, newspaper articles, websites, commentaries by subject matter experts, HumInt reports. Information can be extracted from such data in terms of general high-level guidelines and specific detailed relations. General guidelines are comments such in al-Qa'ida each cell is designed to cover a number of skills or

Hamas is organized functionally and by region. In contrast specific relational data is of the form Usama bin Ladin is the head of al-Qa'ida. Different types of errors are prone to exist in both types of information. By utilizing both types of information a more informed decision about potential actions can be made and the strengths of one type of data can be used to overcome the limitations of the other. However, the granularity of these two types of data is so different that most tools cannot handle both types of data. What is needed is an approach, a set of tools, which can take advantage of both levels of data. This work moves us toward such an approach.

1.1 High Level Data

Current information suggests that the structures of al-Qa'ida and Hamas are different in key ways. For example, information on al-Qa'ida suggests that it is organized in a very distributed cellular form (see table 1). At least, this appears to be the case for the central core of al-Qa'ida although it often links to other terrorist groups by infiltrating and "greening"; i.e., teaching them how to act like the central core, implying support (possibly providing support) if al-Qa'ida best practices are followed, and so on. In contrast, information on Hamas indicates that its structure exhibits a more rigid structure (see table 1) organized in an almost matrix form by function and region. Information such as that shown in table 1 is extracted from subject matter experts, built up over experience, and the quality depends on the number of different experts who are consulted and their views about what factors are important in characterizing groups. Such data, is, in this sense, much more subjective; but, provides a high level view.

Table 1. General Features of Terrorist Groups

Feature	al-Qa'ida	Hamas
Organizational structure	Top-hierarchy with underlying cellular for central al-Qa'ida connected hierarchically to related groups like JI	Matrix – by region and function
Cells	Distributed skills in cells	Same skills in cells
Missions - small	Planned, executed, funded by cell	Planned by function, executed locally, funded regionally
Missions - large	Planned, funded, and executed by multiple cells under temporary hierarchical coordination structure	Matrix planning and funding coordinating execution by multiple cells
Cell orientation	Mission – unlimited number of missions	Function – there are five basic functions
Cell leaders	More experience/ broader knowledge	More experience/ similar knowledge / political connections
Connection among cell leaders	Similarity (historical)	By function and region
Locus of control	Distributed - cells can operate independently for small missions	Predominantly centralized - cells coordinated by regional and functional leader
Directives	Can come from higher up	Always come from higher up
Executive group	Broad	Narrow
Members of executive group (power in terrorist group)	Some cell leaders	Most functional and regional leaders
Political power in community	Varies	Regional leaders are often powerful
Integration with community	Moderate to low	Reasonably high
	Hidden	Infrastructure cells legitimate businesses Operational cells infiltrated into police, military etc.
Connection to other terrorist groups	Hierarchical	Lateral – through intermediaries

Such data can be used to generate an overall picture of the structure. This picture can be augmented when reports indicate who fills what role. In the case of al-Qa'ida the picture would look like that in Figure 1 with Usama bin Ladin taking on the overall lead. Whereas, in the case

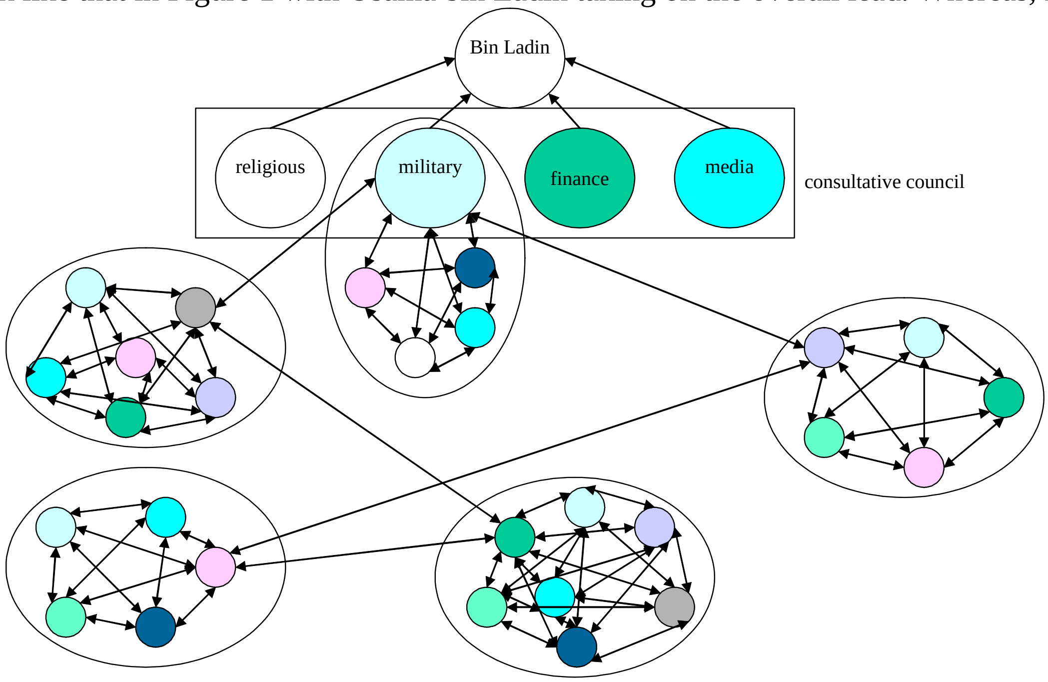

Figure 1. al-Qa'ida Structure

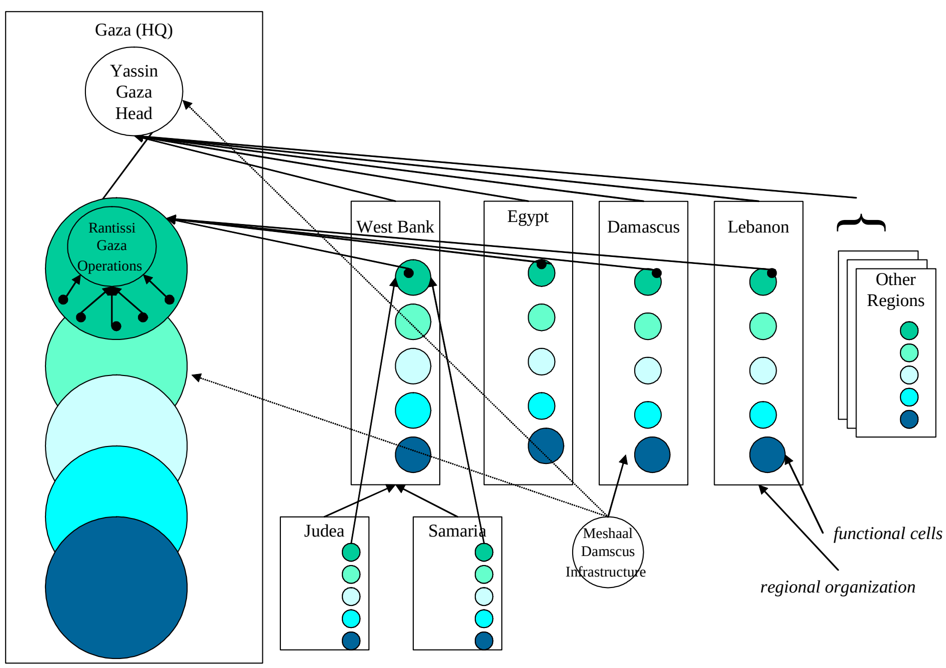

Figure 2. Hamas when Sheik Ahmed Yassin was Alive

of Hamas, when Sheik Ahmed Yassin was alive such additional information would result in a picture such as that in Figure 2 with Yassin taking on the overall lead. In general in these figures only reports to lines are shown. In the case of Hamas, we have supplemented this with two dashed lines indicating the known disagreement of Yassin and Meshaal and the movement of Meshaal from operations in Gaza to Damascus.

Of particular interest from a simulation standpoint is the way in which the cells are organized. In al-Qa'ida the cells can be self sufficient. Many have independent control for their own finance, infrastructure and operations, although there appear to be support cells which can provide fiancé, recruitment and training services. Many cells are mission oriented. One key issue is that connections or ties among cells appear to be predominantly at the leader level whereas there appears to be all-to-all communication within cells. However, the connections among cells may only be activated for particular missions. In contrast, in Hamas there are four operations wings: internal security (Jihad Amman), "popular uprising" (stage violent protests, stone throwing, etc), suicide bomber group (Al-Majahadoun Al-Falestinioun), professional killer group (The Izz al-Din al-Qassam Squads), and an "infrastructure" group that is often composed of domestic finance, domestic recruiting, and religious activities. Each of the functional operational cells has one or more high-ranking officers who report to the Gaza HQ or West Bank HQ (depending on location and sometimes to both). Gaza HQ is more powerful, probably the leaders of that functional branch. For infrastructure the leader of each regional infrastructure cell also reports to the GAZA infrastructure leader. All Gaza infrastructure leaders report to Yassin. Within some regions certain operational cells may be dormant, hidden or sleeping – such as in Damascus, Lebanon, Egypt and other regions like the USA. Thus, although missions are often carried out by cells those cells are coordinated to, tied to, both functional and regional leaders.

1.2 Detailed Data

In contrast to this high level view is the more specific network or individual level data. In this latter case, text analysis can be used to scan for specific relations. Such an analysis might result in a figure like the famous Krebs (2002) – 9-11 hijacking figure – redisplayed in Figure 3. In many organizations, social network analysts collect such data by administering questionnaires. Such an approach is clearly unfeasible for terrorist groups. Alternatively, such networks can be collected from archived data sources such as phone records, newspaper reports, webpages or HumInt. Texts sources can be used to collect relations. Krebs, in constructing the figure displayed as Figure 3, drew on articles in major newspapers (such as Sydney Morning Herald, 2001; Washington Post, 2001).

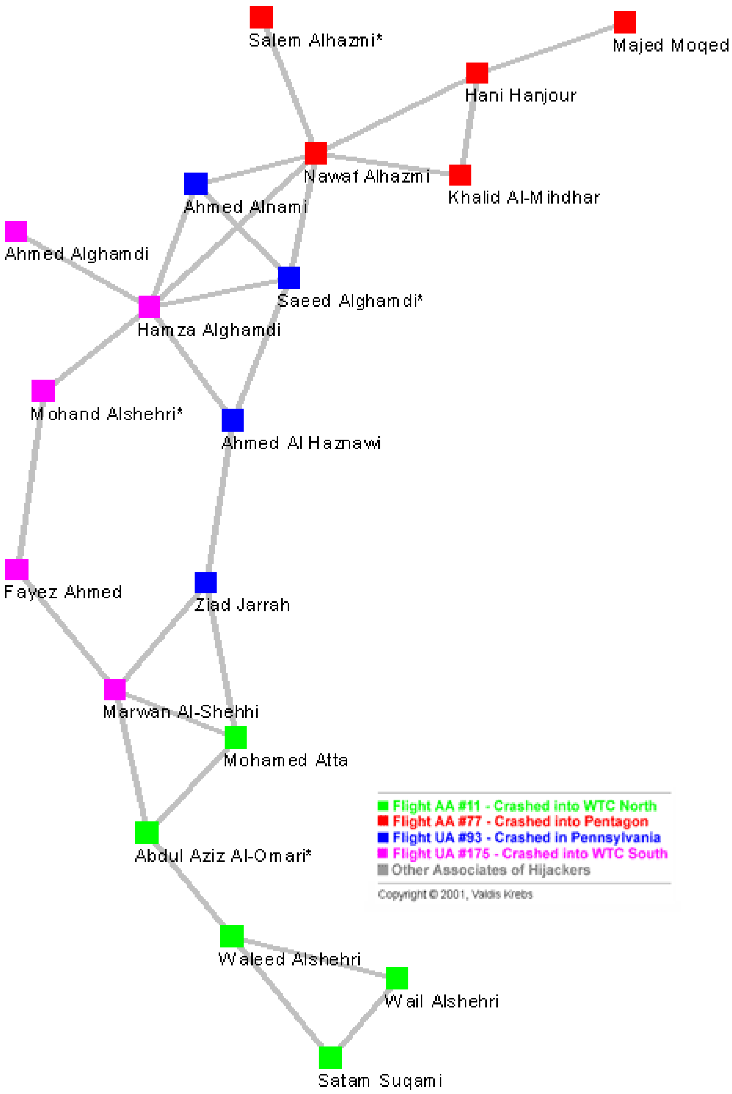

Figure 3. Krebs (2002) 9-11 Hijacking Data, copyright held by First Monday

Krebs, of course, extracted this data manually. Each day he read additional papers and one by one added new ties. There are, however, some text analysis techniques that can semi-automate this process such as AutoMap (CMU: http://casos.cs.cmu.edu/projects/automap/ Diesner and Carley, 2004). However, none of these techniques completely eliminates the need for some human coder intervention. Such tools will facilitate the collection of detailed data.

2 LIMITATIONS OF TRADITIONAL SOCIAL NETWORK ANALYSIS VIS-A-VIE AVAILABLE DATA

Standard social network analysis provides the user with a number of tools for characterizing these networks and analyzing this data. Unfortunately, such tools are in a sense rigid vis-a-vie the kind of data that is likely to be available. For example, in this area there are vast quantities of data on people, events, groups and the diverse relations among them such as finance, authority, and influence. In other words the data is incomplete, inaccurate, dynamic, multi-mode and multi-plex. Further, the fact that many groups are trying to operate in a covert matter, the lack of sufficient public records, the difficulty collecting information and translating it, the large and diverse agendas of the informants leads to data that is incomplete, inaccurate, as well as potentially out-of-date and intentionally wrong. Carley (2003) cited a number of relevant limitations for using the traditional social network analysis approach to examine terrorist groups:

> "Traditionally, social network analysis (SNA) has focused on small, bounded networks, with 2-3 types of links (such as friendship and advice) among one type of node (such as people), at one point in time, with close to perfect information. To be sure there are a few studies that have considered extremely large networks, or two types of nodes (people and events), or unbounded networks (such as inter-organizational response teams); however, these are the exception not the norm. However, such studies are still the exception not the rule. Further, while it is understood, at least in principle how to think about multi-modal, multi-plex, dynamic networks, the number of tools, the interpretation of the measures, and the illustrative studies using such "higher order" networks are still in their infancy relative to what is

available for simpler networks. Finally, many of the tools do not scale well with the size of the network or degrade gracefully with errors in the network; e.g., they may be too computationally expensive or too sensitive to both type 1 and 2 errors."

Many of these limitations are simply technical challenges that new metrics and algorithms can over come. One difficulty that is particularly troublesome traditional social network analysis, however, is the dynamics of these networks. Consider, for example, Hamas. In Figure 2, Meshaal is shown as being associated with the Damascus region but not necessarily with a cell. If at this point he was in a cell it was probably infrastructure. Toward the end of Yassin's life Meshaal was out of favor with Yassin and kept away from him; whereas, prior to that he may have been in operations. Now, after the assassination of Yassin, Meshaal has arisen to be the acting head of Hamas in Gaza, but may well have little power (http://www.debka.com/article.php?aid=813; http://www.debka.com/article.php?aid=812). What is needed is a way of reasoning about such change, the ability to reduce surprise by providing some estimates of the impact of certain changes, and the ability to "pre-evaluate" actions take to mitigate or increase the effectiveness of the opponent. To date, a standard approach here is to attempt to predict change based on the estimates of subject matter experts using largely the subjective high-level data often narrowed to a particular area of expertise. Developing dynamic network analysis is not a simple exercise in the extension or adaptation of existing metrics. Instead, it requires fundamentally new metrics, tools, and theories.

A second major problem is the incompleteness and inaccuracy of the data. Two types of data were discussed – high level general and detailed specific. Both types bring their own problems. The high-level data is in a sense more complete; that is, it provides a broader description of the structure of the underlying terrorist organization, identifies the types of nodes and relations, and paints a picture of the "on-average" relations. It is important to keep in mind that such high level data is often collected by subject matter experts who may have an area of specialty narrowed by time, region, or specific actor. Hence, generating an over-arching picture requires integration across these experts. Further, such high level data is subjective and so potentially over or understates the relative importance or frequency of types of relations. Social network or relational thinking facilitates the collection of such high level data. However, the resultant data is so general that social network analytic techniques cannot be fruitfully applied.

In contrast, the detailed data is eminently suited to the tools of social networks. Such data provides a very detailed picture of the specific connections among specific nodes; but often, for only a subset of the overall organization. The data is likely to be more accurate about the highly central or hub actors than the less central, the actors who are visible in the political context of the community, or who act as leads. Such data, being collected often in a more semi-automated fashion, can be collected to cross over areas of specialty and so not be bound by temporal, regional or actor bounds as it the subject matter expert. As a result, integration is more automatic and data extraction more systematic. Nevertheless, the lack of fully automated tools to extract such data means that data collection is arduous and so researchers often limit the scope of analysis to data that is readily available (such as membership data or information in newspapers) often associated with a specific event – such as Tanzania embassy bombing (Carley et al., 2003 or the 9-11 hijackers (Krebs, 2002). Such detailed data is, in this sense, more objective and so provides more accurate estimates of the importance or frequency of some relations and the networks around some nodes. Nevertheless, there are gaping holes in such data from missing the overall picture. In general, what is needed is a way of combining these two types of data, using each type to mitigate the limitations of the other, and so reaping the benefits of both and estimating the shape and structure of the underlying networks so that the tools of social network analysis can be applied.

3 NETWORK DYNAMICS

As noted, we need to combine these two types of data and we need to, given the combined data, estimate how these networks change. Further, since there are still likely to be missing data and errors in the combined data, we need to be able to place the results in a risk context and estimate how missing data is likely to affect the results. Finally we need to be able to interpret the results, in part, by understanding the characteristics of the key individuals in the network and the network itself.

In this analysis, we start by discussing how the data was combined. This is followed by a discussion of the attributes that characterize actors and what they mean and the tool used to extract those measures (ORA). Then, these networks are evolved using a multi-agent network simulation tool (DyNet). Then, to illustrate the ability to reason about these networks dynamically a series of virtual experiments are run in which various actors are isolated. To interpret the results the characteristics of the actors that are removed or whose position changes are examined.

3.1 Combining the Data

In order to examine the available data using the simulation and networks it is necessary to build a meta-matrix representation for each of the al-Qa'ida and Hamas networks. The meta-matrix is a conceptual representation of network data that combines the social network with other types of networks, such as the knowledge network. The meta-matrix is in fact, a multi-mode multi-plex representation of a network. For this study we focus on three key types of entities – actors, knowledge and groups and the relations among them. To begin with, the high-level general data is used to create the matrices in the meta-matrix with particular attention to the actor-by-actor, actor-by-knowledge, actor-by-group and knowledge-by-group matrices. Then the detailed data is used to adjust overall parameters in the simulation and to augment the connections among those actors being simulated for which the real world analog is known (e.g., the connection between Yassin and Meshaal. Rather than describe the creation of each matrix in the meta-matrix for both terrorist groups, the process is illustrated by describing the creation of the actor-by-group network, the actor-by-actor authority network and the actor-by-knowledge knowledge network for Hamas.

Actor-by-group: For example, we might build a Hamas network in which there is an overall leader and five groups for regions and another five groups for functions. We would then select a number of actors. If more detailed information is used it can be used to inform the number of actors to be simulated, or the ratio of the size of the groups to each other. Assume for the moment that there are only 31 actors, 1 leader, 5 regional leaders, and 25 cell members. Then based on the high level data we would expect a matrix like that in Table 2. To this we can use detailed data to note that Meshaal is part of the infrastructure group in Damascus and that Rantissi is a lead operations person in Gaza. This could be used to add two additional individuals to the table, resulting in 33 total actors.

Table 2. Actor-by-Group

Actor- by-group	Group 1 – Gaza	Group 2 – West Bank	Group 3 – Damascus	Group 4 – Lebanon	Group 5 – Egypt	Group 6 – internal security	Group 7 – popular uprising	Group 8 – professional killer	Group 9 – suicide bombing	Group 10 – infrastructure
Yassin	1									
Gaza Leader	1									
West Bank Leader		1								
Damascus Leader			1							
Lebanon Leader				1						
Egypt Leader					1					
member	1					1				
member	1						1			
member	1							1		
member	1								1	
member	1									1
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member					1	1				
member					1		1			
member					1			1		
member					1				1	
member					1					1
Meshaal			1							1
Rantissi	1					1				

Actor-by-actor: An actor-by-actor binary matrix is created representing the lines of authority. This is shown in table 3. In this case a tie, a 1, indicates that the person in the row reports to the corresponding person in the column. Rows and columns are ordered the same. Again specific ties, such as that between Rantissi and Yassin are added.

Actor-by-knowledge: An actor-by-knowledge binary matrix is created such that the distribution of "facts" (who knows what) are distributed across group members as suggested by the high-level information. The "facts" or types of knowledge are sub-divided into social, regional, and functional. All actors in the same function have roughly equivalent functional knowledge. All actors in the same region have roughly equivalent regional information. Regional and functional leaders are given a little more knowledge than their underlings to represent the impact of training and experience. In addition, regional and functional leaders are given social knowledge of the overall leader Yassin. Yassin is given a sample of both functional and regional knowledge and social knowledge of the functional and regional leaders. For space purposed this matrix is not shown

Table 3. Actor-by-Actor	
Actor- by-Actor	
Yassin	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Gaza Leader	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
West Bank Leader	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Damascus Leader	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Lebanon Leader	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Egypt Leader	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
member	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
member	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
member	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
member	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1
member	0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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member	0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
member	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Meshaal	0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Rantissi	1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Once these matrices are created they can then be analyzed to estimate the properties of the actors, entered as input into the simulation system to estimate performance and possible changes. Further, as new information is uncovered it can be used to expand or alter these matrices thus enabling expectations based on the data to be rapidly updated. Possible changes might be, for the al-Qa'ida network the incorporation of the 9-11 hijackers. Another possible change might be, in the case of Hamas, to alter the proportional sizes of the groups. For example, as there is reason to believe that there are more people in Gaza and the West Bank one might wish to double the number of individuals associated with each of those groups. Since there is reason to believe that there are few individuals in the operations cells in Damascus, Egypt and Lebanon then the number of actors in those cells might be reduced to zero or to, at least, many fewer than in Gaza and the West Bank. Finally, in order to estimate the robustness of the results generated using these matrices one need only randomly permute the matrices by, e.g., adding or dropping a percentage of links (edges) or nodes.

3.2 Characterizing Actors and the Network - ORA

Some actors are liable to stand out in any network for various reasons. For example, they may be highly central in the social network (individual who is connected to most others) or they may be high in cognitive demand (previously called load; with a great deal of demands on their time due to needs to communicate, work on complex tasks, etc.). These and other critical aspects the terrorist network can be identified using ORA. ORA (CMU, http://www.casos.ece.cmu.edu/projects/ORA/index.html, Carley and Reminga, 2004) – evaluates potential organizational risks based upon meta-matrix data. ORA contains a large number of measures of organizational vulnerability based upon various organizational, operations research, and communication factors. Recently, vulnerability measures developed through the analysis of Team X at NASA have been added to ORA. Note, ORA is designed to gracefully degrade in the face if missing matrices. That is, it calculates only those measures that apply given the matrices of data that are available and for many measures has “reduced form estimates” that are calculated only on the available matrices.

	Actors	Knowledge	Tasks	Groups
Actors	Social Network	Knowledge Network	Assignment Network	Membership Network
Knowledge		Information Network /	Needs Network	Core Capabilities
Tasks			Precedence Ordering	Institutional Relation
Groups				Inter-organizational Network

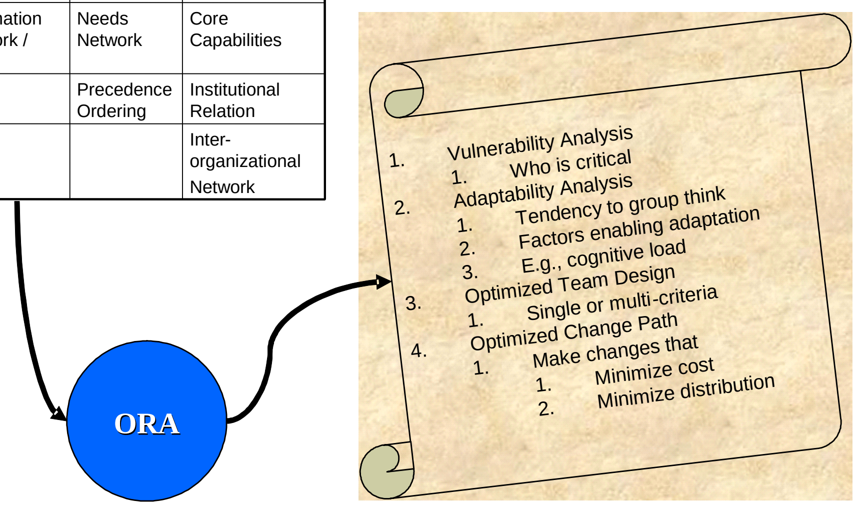

Figure 4. ORA Tool

For al-Qa’ida and Hamas networks developed herein, there are three measures that we find of particular importance in assessing agent characteristics – degree centrality and cognitive demand. Further, there is one measure of the overall network that is valuable – overall complexity (basically density of overall meta-matrix number of ties divided by number of potential ties). These measures have been shown to be valuable in the past when considering how to destabilize and influence networks (Borgatti (2002), Carley et al.; 2001; 2003). It is important to note that if we had other data, such actor to task data, then it would be possible to estimate not only general performance as is done in the next section, but also “congruence” the tendency of the organization to be structured such that the social, knowledge and assignment networks are congruent with, match well with, the needs of the organization and the order of tasks to be done.[1] This is important for most organizations as higher congruence corresponds to higher performance.

When applied to the two networks, some interesting differences arise. See table 4. First, neither group is very complex; i.e., both networks are extremely sparse. In part, this is indicative of major amounts of missing data. However, it is important to note that more detailed data on al-Qa'ida (Sagemen, forthcoming; Krebs, 2002; Carley et al., 2003) also indicate a very sparse network. Thus, this may simply be an indication of a cellular structure in which some cells can be self directed. The case for Hamas, however, is less clear as there are as yet fewer network studies of components of that organization. Second, it is important to note that the formal leaders exhibit different network characteristics. Usama bin Ladin appears to both connect to the most others and to have the most to do. This suggests, purely on the basis of position, that removing him from al-Qa'ida may have more of an impact on the network than removing Yassin from Hamas; but, the removal of either is likely to be destabilizing. It is important to keep in mind that these "predictions" are only guesses based on the structural position of the actor. They do not take in to account the impact of network dynamics.

Table 4. Characteristics of Networks and Key Actors

Characteristics	Meaning	al-Qa'ida	Hamas
Complexity	Very low then probably major amounts of missing data, possibly cells are self directed. Very high then system is tightly coupled and possibly prone to group think.	slightly more complex Overall – very low density	slightly less complex Overall – very low density
Highest in degree centrality	Individual most likely to diffuse new information, isolation of this person will be slightly crippling for a short time.	Bin Ladin	Yassin
Highest in cognitive demand	Individual most likely to be an emergent leader, isolation of this person will be moderately crippling for a medium time	Bin Ladin	Rantissi

3.3 Strategic Change through Actor Isolation - DyNet

The question now is "What is the dynamic profile of these alternative terrorist networks?". Can we do better than guessing what is likely to occur when an actor is isolated? To evaluate the behavior over time of these networks the tool DyNet (CMU: Carley et al., 2003) is used. A conceptual overview of DyNet is provided in Figure 5.

DyNet is a multi-agent network model of network natural and strategic evolution. It is intended to be a desktop tool for reasoning about dynamic networked and cellular organizations under varying levels of missing information. The purpose of the DyNet project is to develop the equivalent of a flight simulator for reasoning about dynamic networked organizations or groups by blending ideas from computer science and social networks. As a result, DyNet is a reasoning support tool for reasoning under varying levels of uncertainty about dynamic networked and

[1] When measures such as congruence are available, it is possible to use ORA to estimate the optimality of the proposed network. The optimum organizational structure is calculated using a general multi-criteria optimization function available within ORA (Carley and Kamneva, 2004).

cellular organizations, their vulnerabilities, and their ability to reconstitute themselves. Using DyNet analysts are able to see how the networked organization is likely to evolve if left alone, how its performance can be affected by various information warfare and isolation strategies, and how robust these strategies are in the face of varying levels of information assurance.

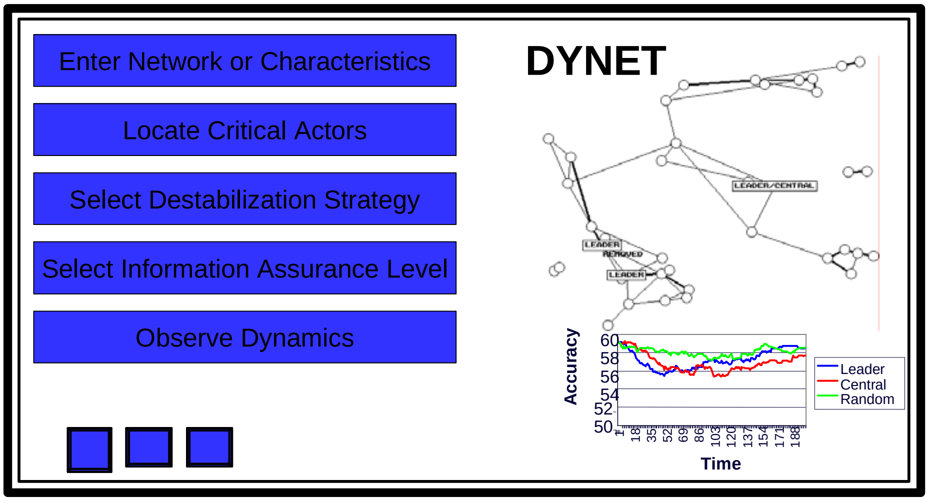

Figure 5. Conceptual View of DyNet

The basic cycle in DyNet is that actors interact, send and/or receive information or queries. The flow of information effects learning on the part of the actors which in turn alters who is likely to interact with whom. Two key factors influence interaction – homophily and information seeking. In the first case, actors are more likely to interact just in case they have more in common relative to what they have in common with others. In the second case, an actor is more likely to seek another out if the first actor thinks that the other knows more (of what he/she does not know) relative to all others. These mechanisms are related to, and predictive of, social and advice giving networks (Carley, 2002).

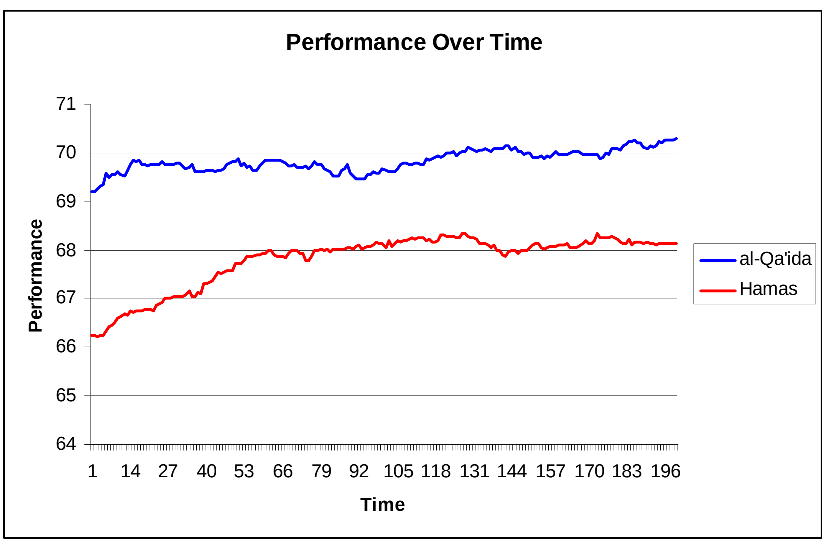

Figure 6. Expected Performance

DyNet takes the meta-matrix as input and then predicts group and individual outcomes such as performance, information diffusion, and development of consensus. Herein, we have done this in a Monte-Carlo fashion such that each of the terrorist groups was simulated multiple times and the results averaged. Statistical tests reveal that the lines shown in Figure 6 and 7 are significantly different. The resultant behavior of the two terrorist networks is shown in Figure 6. Basically, what we see here is that DyNet is predicting that, on average al-Qa’ida will exhibit higher performance than will Hamas.

What is likely to happen if the formal leader is removed. This question too can be addressed with DyNet. Here, the two networks are re-simulated but this time with the leader removed. See figure 7. There are two main things to note. First, for Hamas, the removal of the leader actually leads to improved performance. Since many top members of Hamas are known to be more militant than Yassin, one might expect this to mean increased violence. As a sign of validation, note that since Yassin's death the activity level in Hamas has increased. Second, for al-Qa'ida the removal of the formal leader degrades performance.

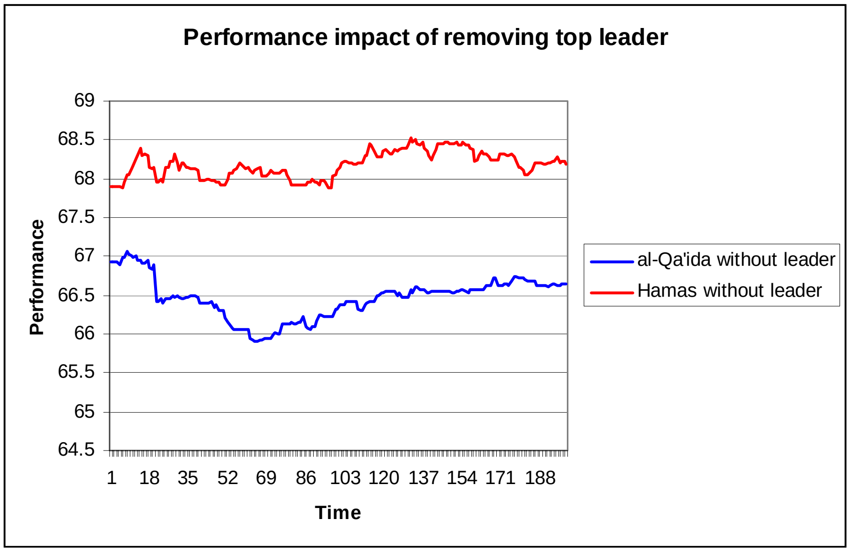

Figure 7. Expected performance after removal of formal leader.

Of course, formal leaders tend to be hard targets. We might ask, what would happen were to random cell members to be isolated. In this case (not shown) the simulation suggests that al-Qa'ida's performance drops but it recovers. Whether the drop is more or less than in Hamas appears to depend on the structural position of the actors who are isolated. In particular, removal of mid-level actors, such as regional leaders who are also functional leaders in Hamas appears to degrade performance.

A second question we might ask is, who will emerge as the formal leader after the formal leader is isolated. For the data used here, it is difficult to predict exactly who that will be, in part as there is little information on specific individuals. The DyNet program does make some suggestions. In general individuals with high cognitive demand emerge as leaders, at least temporarily. In the case of al-Qaida there are a number of actors with roughly comparable cognitive demand who could emerge leading to a multi-headed hydra. In the case of Hamas, DyNet suggests that Rantissi is likely to emerge. A word of caution is necessary, however. These simulations were done not taking into account the historic and negative ties to Meshaal. Were we to add those ties, we would see that the performance of Hamas still improves when Yassin is removed, but that it is now difficult to tell which of Rantissi or Meshaal will become the formal leader. In this secondary analysis, both Rantissi and Meshaal are emergent leaders and play temporarily pivotal roles.

4 POTENTIAL RISKS

Error in network data can take the form of missing or additional nodes or edges (ties). We have begun an analysis of the impact of such errors on correctly estimating centrality and cognitive demand in general (correlation) and in specific (locating the top person) (Carley, Reminga and Borgatti, 2003). This analysis, to date, has been done on Erdos random graphs. Preliminary results indicate that for Erdos random networks, the ability to correctly estimate the individual who is highest in degree centrality or cognitive demand degrades linearly with the amount of error. The degradation in estimation appears faster for cellular networks and may not be linear. This is critical as for random networks all destabilization tactics (such as isolation of the individual that is highest in centrality or cognitive demand) have approximately the same effect; but for cellular networks cognitive demand is more effective.

There are two issues to apply this result to the foregoing work. First, how much data is missing. At a detailed network level, the pictures are missing well over 50% of the data at the actor level. At the component or group level, the missing data is possibly closer to 10%. As such the results are more likely to be right for overall group effects than individual. In other words, it is likely that the predictions about the impact of removing a leader are more likely to be right than predictions about their successors. The second issue is, to what extent is the missing data uniformly missing from the network. Here we note that due to the attention of the media on the formal leaders, and due to the ease of finding general than detailed data, again it is more likely that the results surrounding bon Ladin and Yassin are right compared to those for, e.g., Rantissi.

5 LIMITATIONS AND FUTURE WORK

While the work presented moves us a fair way to understanding and predicting the dynamics of these networks, it still does not handle a variety of issues. For example, the current system is weak at linking regional based specialties to actors. An example of regional specialties is that weapons deliveries to Hamas go from Egypt, through either "normal" smuggling channels or underground tunnels under the border (Katz, 1999). Such factors are currently not possible to simulate in DyNet.

Another critical limitation is that the current technologies cannot account for behavior related to the social or political context. In terms of social context, for example, in Hamas, the infrastructure cells provide services to the local population (such as running religious schools - where children parade on holidays in fake suicide vests) (Katz, 1999). Each of the three sub-services in the infrastructure cell probably has its own heads who report to the chief of infrastructure. As to political context, the current approach has difficulty linking state level actions to the individual. For examples, in the case of Hamas, Khaled Meshaal is the leader of the "political wing", lives in Damascus and enjoys full legitimacy from the Syrian government, including luxurious headquarters in the center of the city. As another example, Jordan does not endorse Hamas (Katz, 1999). Such social and political context information is difficult to utilize currently, yet is clearly important from an overall perspective.

It is clear that future system needs to consider how to bring such contextual information in. Doing so, we note, is non-trivial. At CMU in the CASOS lab we are currently exploring possible ways of linking such context information to DyNet. At the technology level it requires multi-level modeling integrating micro and macro modeling tools which is an unsolved problem. At the theoretical level, little is known about individual differences in balancing social, political and group level concerns and goals. At the empirical level, the validity, collection and bias issues at each level are distinct and little is known about how to calibrate data across levels.

Perhaps the one item that is likely to have the most impact on the model and the analysis is the incorporation of negative linkages. In the case of Hamas, when previous connections to Meshaal were included Meshaal emerged along with Rantissi as an emergent leader. In al-Qa'ide most of the previous work shows that elimination of one leader leads to multiple emergent leaders. In this work, such individuals emerge due to the high level of cognitive demand they are under and so their ability to act as change agents due to their structural position (position in the network). However, as political and military science informs us, lines of alliance as well as lines of hostility are critical in effecting political change. Moreover, understanding such linkages enables alternative attack strategies (like pitting one side against another) also to be examined. As negative as well as positive linkages are added to DyNet we expect, therefore, to be able to facilitate examining political as well as structural change.

In summary, an approach for taking incomplete and potentially inaccurate data and reasoning about change has been described and illustrated. Key features of this work include: using detailed network data to supplement high level views of organizations to create a composite image, using network metrics for multi-mode, multi-plex data to characterize key actors and the network itself, and using multi-agent simulation to predict change in the composite network view over time. Uncertainty is handled by using two types of data to reduce uncertainty, running the model in a Monte-Carlo fashion to determine the robustness of the results, and examining the robustness of the results under adding and dropping nodes and edges in the underlying networks.

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