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SPECIAL FEATURE: SOCIAL NETWORKS

Social Networks, Risk-Potential Networks, Health, and Disease

Samuel R. Friedman and Sevgi Aral

Driven in part by recent research in the epidemiology and prevention of human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) and other sexually transmitted or blood-borne infections, the topic of social networks has become the focus of considerable interest and discussion. Networks offer the promise of a way to move the analytic focus one step "above" that of the individual, to consider the patterns through which individuals are linked in small groups and through them in large "sociometric" networks. Thus, network approaches offer a way to apply the analytic insights and computerized techniques of systems theories to studies of the flow of social support, social influence, and infectious diseases through populations and, as well, among organizations.

Before going on, though, it might be useful to explain what a network is, what kinds of networks are of most interest, and what some key terms used in network analysis are. This can be done in mathematical language, such that a network is a set of nodes plus the set of connections linking some or all of these nodes to each other. It might be more useful, however, to use a few diagrams to explain these concepts in specific contexts relevant to the study of health and disease.

NETWORKS: AN INTRODUCTION

What are networks? Here, we introduce some key network concepts and then briefly outline how networks and norms may affect behaviors and infection probabilities.

A *risk-potential* network is defined as a pattern of risk-potential linkages among a group of people. A risk-potential linkage is a tie between two people that can spread infection if the infectious agent is present. For HIV infection, two basic risk-potential linkages are having sex together and injecting drugs together. Although it is true that such behaviors need not involve meaningful risk of HIV transmission (for example, if two people inject using totally separate equipment and drug mixtures), it can often be useful to think of sex and injection drug use (IDU) as general risk linkages and then to study subsets of linkages as subsidiary analyses. An example of this for sexually transmitted diseases for which condoms offer effec-

Samuel R. Friedman is with National Development and Research Institutes, Inc., New York City, New York. Sevgi Aral is with the Centers for Disease Control and Prevention, Atlanta, Georgia.

Correspondence: Samuel R. Friedman, National Development and Research Institutes, Inc., Two World Trade Center, 16th Floor, New York, NY 10048.

tive protection would be to look only at sex without a condom as defining a risk-potential linkage. (Another justification is that reports on consistent and correct condom use and syringe-sharing may be subject to social desirability bias.) Thus, risk-potential network analysis is related to contact tracing, but does not limit itself by starting with infected cases.

Thinking in terms of networks involves building larger patterns from linkages between pairs of people. An *egocentric network* approach considers only the direct linkages of a given person ("Ego"). Operationally, this usually relies entirely on Ego's self-reports about his or her network. In Diagram 1, Ego names five network members. Risk-potential linkages with network members are indicated as lines between boxes. Here, they could represent sexual ties, IDU ties, or both. If, on the other hand, we are interested in Ego's social network, we might ask Ego to name friends or people he or she respects or who provide social support. In this case, Diagram 1 would describe Ego's social network. Most risk-potential linkages are social linkages, but risk can occur without social interaction. An example is injecting drugs with a used syringe picked up from the floor of a shooting gallery.

Egocentric network data can be analyzed in two ways: (1) as a subject's individual attributes; (2) as sets of relationships. In Diagram 1, we could analyze five separate two-person relationships, each including Ego.

Sociometric networks consist of a set of people and the entire panoply of linkages among them. Diagram 2 (adapted from data in Friedman et al.[1]; names are fictitious) presents this schematically. It consists of a component of six members, a second component of seven members, a larger component, and an unlinked participant (Maria). A component (sometimes called a "connected component") is a set of people who are all linked to each other, although perhaps only through a multi-person path. Two components are defined as separate if no one is a member of both.

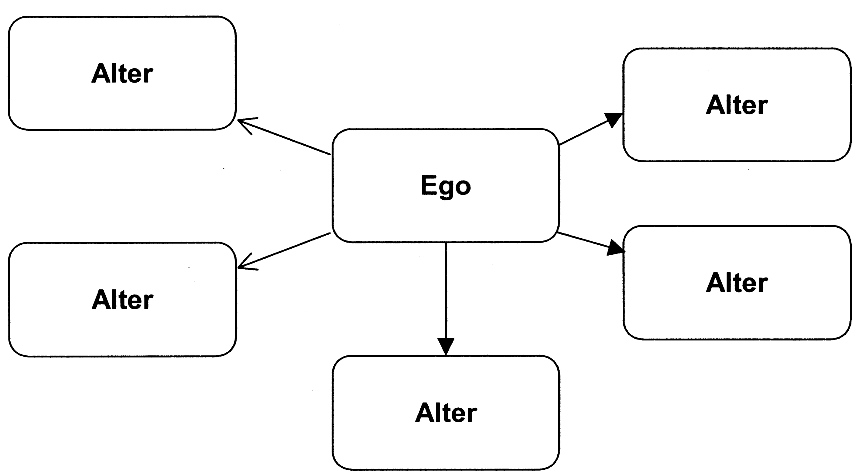

DIAGRAM 1. An egocentric network.

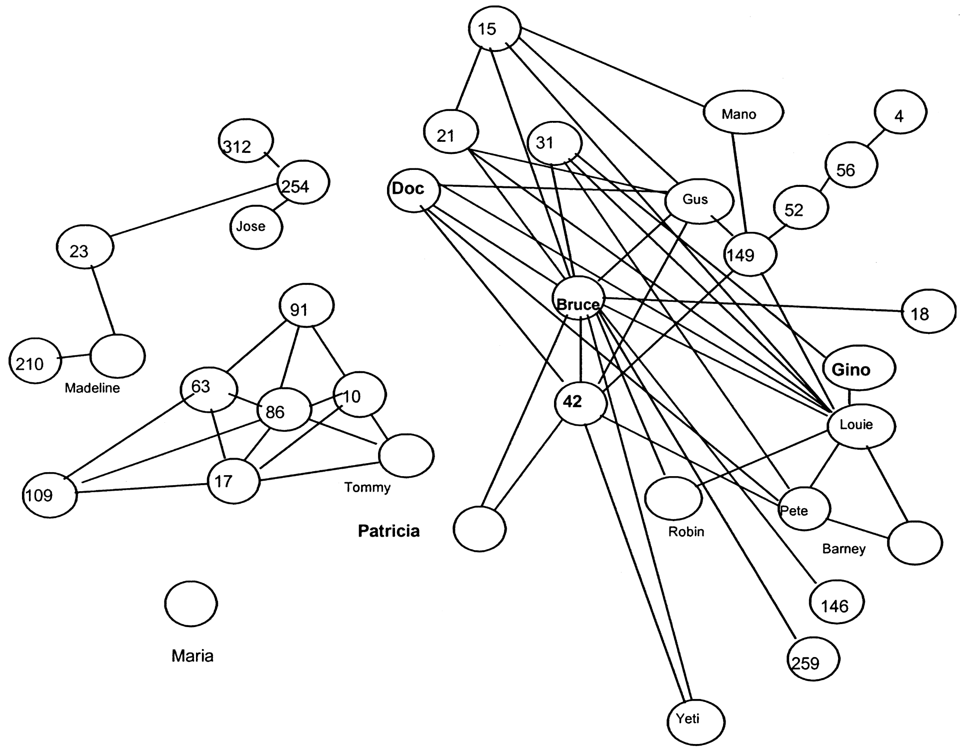

DIAGRAM 2. Sociometric networks.

We suggest (see Diagram 2) that

- Sociometric risk-potential networks can spread infections through a community, including from IDUs to youth. If Doc is an infected IDU, infection could spread through the large component to Gino and Patricia.
- Social networks can spread messages, norms, social support, and influence through a community.[2]
- Until a sexually transmitted infection (STI) enters a component, the isolation of the network may protect its members. But, component members are at risk if any member becomes infected. STIs can spread rapidly in a "microstructure" like the seven-member component due to their high level of interaction. (Microstructures are patterns of tight interconnection. Rothenberg et al.[3] present a cogent example of how microstructures were involved in a syphilis outbreak.)
- To the extent that risk-potential networks are shaped by racial/ethnic mixing patterns, this may lead to differential rates of prevalence and incidence by race/ethnicity.[1,4–6]
- Egocentric risk-potential networks are the proximate potential sources of infections. Thus, the effects of larger-scale networks on individuals occur, in part, through their immediate friends and partners (egocentric networks). In Diagram 2, infections or social influence may reach Patricia from the larger part of the big component, but if so, it will be through Bruce or 42 (members

of her egocentric network who link her to the larger network). Thus, egocentric networks may mediate sociometric network effects on an individual.

NETWORKS AND HEALTH: FIVE PAPERS THAT SHOW SOME OF THE PROMISE OF NETWORK ANALYSIS

Three of the articles in this special issue exemplify classic models of how risk-potential network analysis can be used in the study of disease transmission. Jolly et al.[7] provides a useful review of literature based on studies of STIs. Much of this research has taken data from contact tracing in which index cases are those who present at a medical facility with an STI, the named sexual partners of these index cases are then contacted for testing and treatment, the partners of the partners are then contacted, and so forth. Jolly et al. compare network data produced by such contact-tracing procedures for patients with chlamydia in two moderate-size cities (Colorado Springs, CO, and Winnipeg, Manitoba, Canada). This comparison is intriguing. It shows both similarities, such as the absence of microstructures in each city, and differences, such as the presence of more components (i.e., sets of persons who are all linked to each other directly or indirectly) of relatively large size in Winnipeg. These patterns contrast with the complex microstructures that Rothenberg et al.[3] found to contribute to a syphilis outbreak in Georgia and to the much larger sizes of the largest components in earlier snowball-sample studies of sexual and drug risk-potential networks in Colorado Springs[8–10] and in IDUs in New York City.[1] (Snowball risk-potential network studies start with index subjects who may or may not be infected with any given agent and then follow their risk-potential networks in a way analogous to contact tracing, but with one major difference: They do not stop at uninfected partners, but attempt to interview their partners as well.)

Rothenberg et al.[11] attempt to conceptualize the "risk environment" using a combination of behavioral characteristics (e.g., injecting drugs), egocentric network characteristics (having IDUs as sexual partners), and social status proxies for these other characteristics (e.g., being a gay male as a proxy for high-risk sex with high-risk partners). Like Jolly et al.,[7] they use comparative data from two cities—in this case, Atlanta, Georgia, and Flagstaff, Arizona. Interestingly, they find that their overall risk index has little power to explain HIV serostatus, with one exception: Men who have sex with men have a higher HIV prevalence than other subjects. The implications of this finding are not easy to explain. There are clear possibilities for unreported risk by subjects to have led to misclassification errors. Also, the relatively low HIV prevalence in Atlanta (and even lower in Flagstaff) suggests that there might not be enough HIV present in networks (other than those of men who have sex with men) to use it to validate the risk index. Based on the arguments in Friedman et al.[12] that HIV seroconversion is best predicted by membership in pockets of infection in cities with low HIV prevalence (whereas behaviors are good predictors where HIV prevalence is 20% or more), we would speculate that the HIV epidemic in Atlanta is still primarily confined to men who have sex with men. This, however, does not explain why this has been the case, how and if there might be an outbreak among IDUs, or how such outbreaks might be prevented.

Riolo et al.[13] provide an example of cutting-edge modeling tools that can use network concepts and data together with characteristics of agent/host interaction (e.g., duration of infectious disease and, by extension, primary infection vs. less-infectious periods for HIV) to study patterns of disease transmission in hypothesized communities with given parameters. Such models rely, in part, on the somewhat tautological aspect of network logic for sexually transmitted infections or blood-borne infections among IDUs. That is, if accurate data could be obtained about the precise timing and accurate microbehavioral details of each sexual or injection event that occurs in a community, then a probabilistic mathematical model should be able to simulate the distribution function for probabilities of different epidemic outcomes. Such models, once developed, have a number of useful applications. One of these uses is particularly relevant to large and rather expensive empirical network studies such as those described by Jolly et al.[7] and Rothenberg et al.[11] These empirical studies are really case studies, with each city being one case. Simulations may be able to help us understand the extent to which the findings of such studies were rare events versus the extent to which they should be considered typical.

The articles by Jolly, Rothenberg, Riolo, and their colleagues all focus on risk-potential networks and their relationship to infectious disease transmission. Kawachi and Berkman,[14] in contrast, focus on social support networks. They provide a brief, but cogent, review of literature and issues involved in social support and selected aspects of mental health; they discuss pathways by which social support can contribute to mental health directly and also by providing a buffer against stresses and disruptive life events. They discuss evidence that women, the elderly, and the poor may benefit less from social support networks than do men, the nonelderly, and the nonpoor and suggest that this may be because social networks can themselves involve obligations, stress, and regulation by others—with these negative processes more likely to accrue to women, the elderly, and the poor. They touch on, but do not address, an issue that may be important for some of the health concerns raised by the papers on risk-potential networks and disease transmission: Some social networks can involve the proverbial "bad companions" who can lead their friends into high-risk situations and behaviors such as drug use, group sex, or the sex trade. Kawachi and Berkman also discuss sociometric networks and community embeddedness as social capital, suggesting ways in which these concepts let us analyze interactions in concentric rings of increasing distance from the individual level of analysis. Their focus is primarily on the positive ways in which social support networks, involvement in the community, and the level of social capital in a community can reinforce healthy outcomes. We would point to the other side of this as well: Neighborhood and community structures can be sources of vulnerability as well as strength. Much research is needed on how these levels of analysis and their related social forces can affect (1) prevalence of high-risk behavior, (2) risk-potential network patterns, and (3) efforts to mobilize effective harm-reducing activities and norms to reduce social, infectious, or pollutant threats.

Network analysis has also been widely used in organizational studies and in studies of organizational networks within cities, industries, or nations. Kwait et al.[15] present a useful network analysis of links among organizations that provide medical and social services to persons living with HIV in Baltimore, Maryland. Most of the linkages among these organizations are related to client referrals or to the sharing of information about shared clients. Other links, such as formal alliances and joint projects, also occur. The authors provide a wealth of descriptive material that is likely to be very useful locally; this provides a useful example that might help improve services in other cities. As the authors discuss, however, this article is clearly but one step in a much broader agenda that should study whether "locational" characteristics of organizations in organizational networks affect the quality of services they can provide, whether the overall description of interorganizational networks is similar between cities or varies, and how such variations affect service delivery and outcomes for patients and for nonpatients who should be receiving services.

FURTHER THOUGHTS

Beyond the articles published here, there are a number of other important issues in using networks to study and intervene in heath-related matters that bear some mention. One of these deals with network interventions. If risk-potential networks affect disease transmission, then the usefulness of network analysis is determined at least in part by whether it suggests useful interventions. Similarly, if social networks affect mental health and/or norms and behaviors, then interventions into social networks should be able to improve mental health, mobilize normative pressures against high-risk behaviors, and/or reduce risky behaviors. A number of interventions have in fact been developed with these issues in mind. Kawachi and Berkman[14] discuss some of the relevant research on social support interventions. Latkin[16,17] developed an intervention that used group sessions with index cases and members of their egocentric networks to encourage lasting behavior change. Later, Latkin et al.[18] used a peer leader network intervention model to encourage risk reduction among IDUs. This drew on earlier peer leader models developed by Kelly et al.[19] for HIV risk reduction among homosexual men and by Wiebel[20] to reduce HIV risk behaviors among IDUs.

Further research is needed into the interactions between social networks and risk-potential networks. Some of this research will focus on how high-risk or low-risk sections of risk-potential networks recruit members from each other, which can also be conceptualized as how risk-link formation and risk-link dissolution are shaped by social network variables. Some will focus on patterns of normative content and pressure and how these are distributed across risk-potential networks and social networks. A third strand will pick up on concepts from social movement theory (in which social network ties are viewed as crucial in movement recruitment and mobilization) to study how efforts to mobilize high-risk networks for less-risky behaviors or to mobilize local communities can be more effective in their efforts to assist those who are sick.

Another issue concerns how urban structures, economic forces, social policies, policing patterns, and other "macro" variables shape sociometric risk-potential networks (and, perhaps, how they shape social networks of various kinds as well). Interest in this topic in relation to sociometric risk-potential networks is in part derived from a certain skepticism about the feasibility of "direct" efforts to reshape sociometric risk-potential networks. Part of this skepticism is based on a belief that it takes so long to collect data on such networks that the individuals or small groups who were the most central or who were potential bottlenecks—and who thus are appropriate targets for interventions[1,21]—will no longer be so important by the time they have been identified. Another part of it is based on the belief that there are strong reasons why networks are structured as they are, and that health-related messages to network members may not be very effective in causing sexual or drug-using partnerships to change. On the other hand, to the extent that sociometric risk-potential networks are more or less dangerous due to their social environments (e.g., due to policing patterns that produce a need for secretive networks organized around shooting galleries or group sex parties), then changing these environments might enable networks to reshape into lower-risk configurations.

Conducting such studies of how larger environments are related to network structures and dynamics is challenging. It requires comparative data about networks in localities with different environments. As discussed above in relations to the Rothenberg et al.[11] and Jolly et al.[7] articles, it is difficult to compare networks across cities. Methodological research is needed to determine how to use standard recruitment procedures and standard procedures to elicit the names of partners from subjects so that procedural differences will not bias these comparisons. Theoretical development is needed on what kinds of socioeconomic and policy environmental structures and processes might shape risk-potential networks and social networks in a locality. Finally, these methodological and theoretical innovations need to be combined into efficient multisite research designs.

Thus, the field of network research in public health is really just at a beginning. It is our opinion that this beginning offers promise for improving health and responding to HIV, sexually transmitted infections, and other epidemics.

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