Exploring the Role of Social Network Structure in Disease Risk among U.S. Long-haul Truck Drivers in Urban Areas

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Objective: Using mixed methods, we explored properties of long-haul truckers' social networks potentially influencing STI/BBI acquisition and transmission. **Methods:** We recruited inner-city drug and sex network members (N = 88) for interviews. Blood and urine samples and vaginal swabs were collected to test for STIs/BBIs. Data were collected on participants' role in the network (trucker, sex worker, or intermediary), sexual and substance-use behaviors, and dyadic relationships with drug and/or sex contacts. We analyzed network data using UCINET. **Results:** Data revealed 2 major network clusters (58 male truckers, 6 male intermediaries, and 24 female sex workers; 27.3% STI/BBI positive). Overall, 18.8% of network members had more than one type of risky relationship with the same person (multiplexity), 11.4% of dyads were between 2 STI/BBI positive people (assortative mixing), 36.4% were between one STI/BBI positive person and one negative person (disassortative mixing), 44.3% of people were connected to more than one person who was STI/BBI positive (concurrency), and 62.5% of nodes were just one path removed from an STI/BBI positive individual (bridging). **Conclusion:** Despite only 27.3% of the network being STI/BBI positive, our results revealed network characteristics (and potential intervention points) that amplify risk of disease spread within trucker-centered networks.

Key words: sexual networks; transmission networks; truckers
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Social networks play a critical role in the proliferation of substance use and risk-laden sexual behaviors that can facilitate the spread of sexually transmitted and bloodborne infections (STIs/BBIs).[1,2] Given that STIs are mainly transmitted through intimate contact between infectious and susceptible individuals, the pattern of disease diffusion through populations traces the structure of social networks.[3] Who partners with whom, how partnerships are maintained, and the larger networks they are embedded in have defined STI acquisition and transmission, and therefore, directly relate to a person's risk of infection.[4]

Transient populations, such as long-haul truck drivers in the United States (US), are especially vulnerable to disease risk.[5] Truckers are disproportionately exposed to individual-level chronic stressors that often lead to substance use and sexual risk taking, including excessive work hours and disrupted sleep patterns, time pressures, social iso-

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lation, unhealthy dietary patterns, inadequate access to affordable, quality healthcare, and work-life conflicts.[6]

In addition to individual-level stressors, trucker-centric urban settings (eg, truck stop parking lots, low-budget motels), have the capacity to render truckers and their network contacts vulnerable to multiple risk exposures due to increased risk-taking activities in these locales.[6] Typically trucker networks are composed of truckers themselves, along with a subgroup of people (eg, female sex workers and intermediaries) who account for disproportionately high numbers of contacts with truckers within the network, most notably in trucker-centric urban settings.[7] Because the core individuals of these risk networks (sex workers and intermediaries) are primarily non-transient persons permanently settled in the area, they stabilize the network while also perpetuating the spread of disease by having a multitude of contacts in an established geographic location.[7] These risky network structures can persist in geographic locations for long periods and can exacerbate risk for those traveling through, including truckers.[8,9] This is especially problematic because truckers often engage recurrently with these persons due to their stability in the area, increasing pseudo-security that can lead to unprotected sex and increased risk for disease spread.[10,11]

Empirical evidence corroborates the importance of key social network properties in increased infection risk and spread.[12-14] Common network properties in the study of disease spread include multiplexity (having multiple types of relationships with the same person),[15] assortative (connecting with someone based on similar characteristics) and disassortative mixing (connecting with someone who is different in some way),[16] concurrency (having multiple overlapping connections within the same network),[17] and bridging (being the connection point between 2 otherwise unconnected people in a network).[18] The social and sexual networks of long-haul truck drivers have been implicated in ongoing STI/HIV transmission spikes in less developed areas of the world;[5,19] however, there is less investigation of social network properties in relation to STI transmission and endemicity in inner-city locales in the US.[20,21] Thus, the purpose of this study is to explore properties of US truckers' social networks that potentially influence STI/BBI acquisition and transmission in inner-city Atlanta, Georgia. Specifically, we used a mixed-methods approach to examine multiplexity, assortative and disassortative mixing, concurrency, and bridging within this network of truckers, sex workers, and intermediaries.

METHODS

Participants and Procedures

Data for this paper come from a large mixed methods ethno-epidemiological study on the sex and drug exchanges of US long-haul truckers.[21] This particular investigation used interview data collected in socioeconomically depressed areas of inner-city Atlanta, as well as serological test results, to construct social networks consistent with drug and sex exchanges among long-haul truckers and their contacts.

Before recruiting persons for interviews, researchers engaged in non-participant observation to identify geographic locations and key people within these locations that could be important to the study of trucker networks. This observational period was followed by efforts to build trust with community members via informal conversations and socio-spatial mapping in and around truck stops to ascertain the potential pathways of truckers' STI/BBI risk.[21] In doing so, the research team learned of prominent locales where drug and sex exchanges occurred, as well as prominent network members within these locales. Once these community members were identified and engaged, several focus groups were conducted with truckers, female sex workers, drug suppliers, and community gatekeepers to uncover prevalent risk domains and develop interview guides to be used in the next phase of the study.

Using respondent-driven sampling (RDS), participant recruitment was initiated with 9 female sex workers and 3 intermediaries (individuals who often work near truck stops or gas stations and provide various services for truckers, including polishing wheels, running errands, or procuring drugs or sex workers for truckers)[6] identified during focus groups. RDS is a type of sample recruitment that uses a group of initial network members, known as indexes, to identify and connect researchers to more transient or hidden network members for data collection.[22,23] Previous research on hard-to-

Figure 1
Sample of Interview Questions Used to Create Relational Edge Lists

DYADIC RELATIONSHIPS WITH RISK PARTNERS

IF NOMINATED BY A SEX CONTACT

1. ___ told us that you and s/he have had sex. Is this true?

2. Do you also ***(use drugs with)*** or ***(buy from/sell to)*** ____? If yes…which is it?
   [IF YES, ask ?s 55-62 also]
   [IF NO, after ?54, go to ?63]

3. On a scale from 1 (not at all) to 5 (very well), how well do you know ___?

4. On a scale from 1 (not at all) to 5 (very much), how much do you trust ___?

5. How regularly do you have sex with ____?

6. In the last 3 months, how many times did you have sex with ___? When was the last time?
   [NOTE: If subject can't remember last THREE months…work with him for last month, a week, a day…trying to get the longest amount estimated]
   a. From these, how many were vaginal, anal, and oral sex?

   b. How often did you use condoms on a scale from 1 (never) to 5 (always)?
7. For which sex acts do you use condoms with ____?

8. Where do you usually have sex with ___?

9. How do you usually pay ___ (money, drugs, rides, food, other)?

10. Have you ever paid ___ more for sex without a condom? Why?

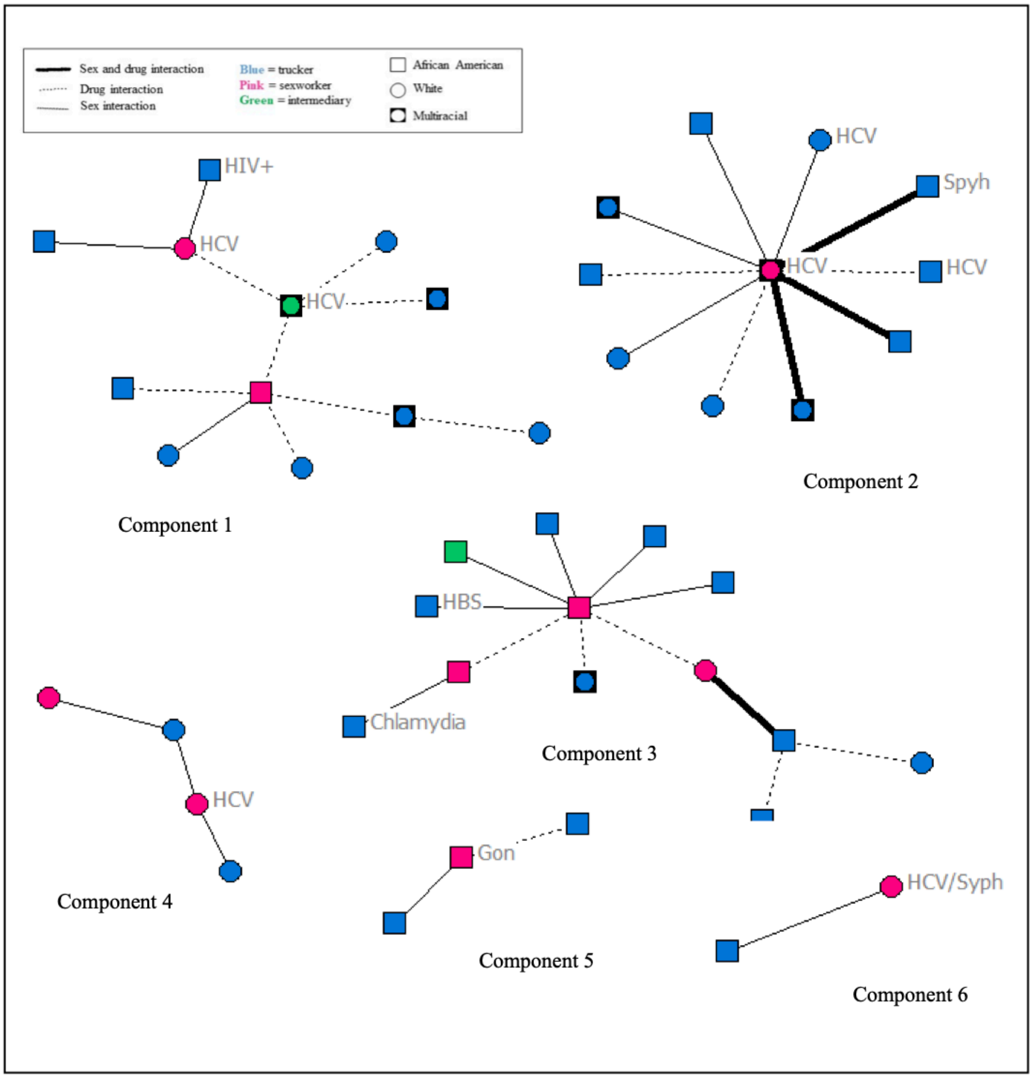
11. To the best of your knowledge, in the last 3 months…how many other people has ___ had sex with besides you?

12. To the best of your knowledge, has ___ ever had any STDs?

13. To the best of your knowledge, has ___ ever tested positive for HIV or been diagnosed with AIDS?

reach populations, injection drug users and persons at risk for HIV infection, support RDS as a means to identify important people within a subgroup of the population, particularly in social network research.[24-26] These 12 indexes who were identified in focus groups and selected due to their stability in the community led researchers to truckers with whom they engaged in drug and/or sex transactions. Whereas we initially recruited a total of 112 trucker network members, arrests, incarceration,

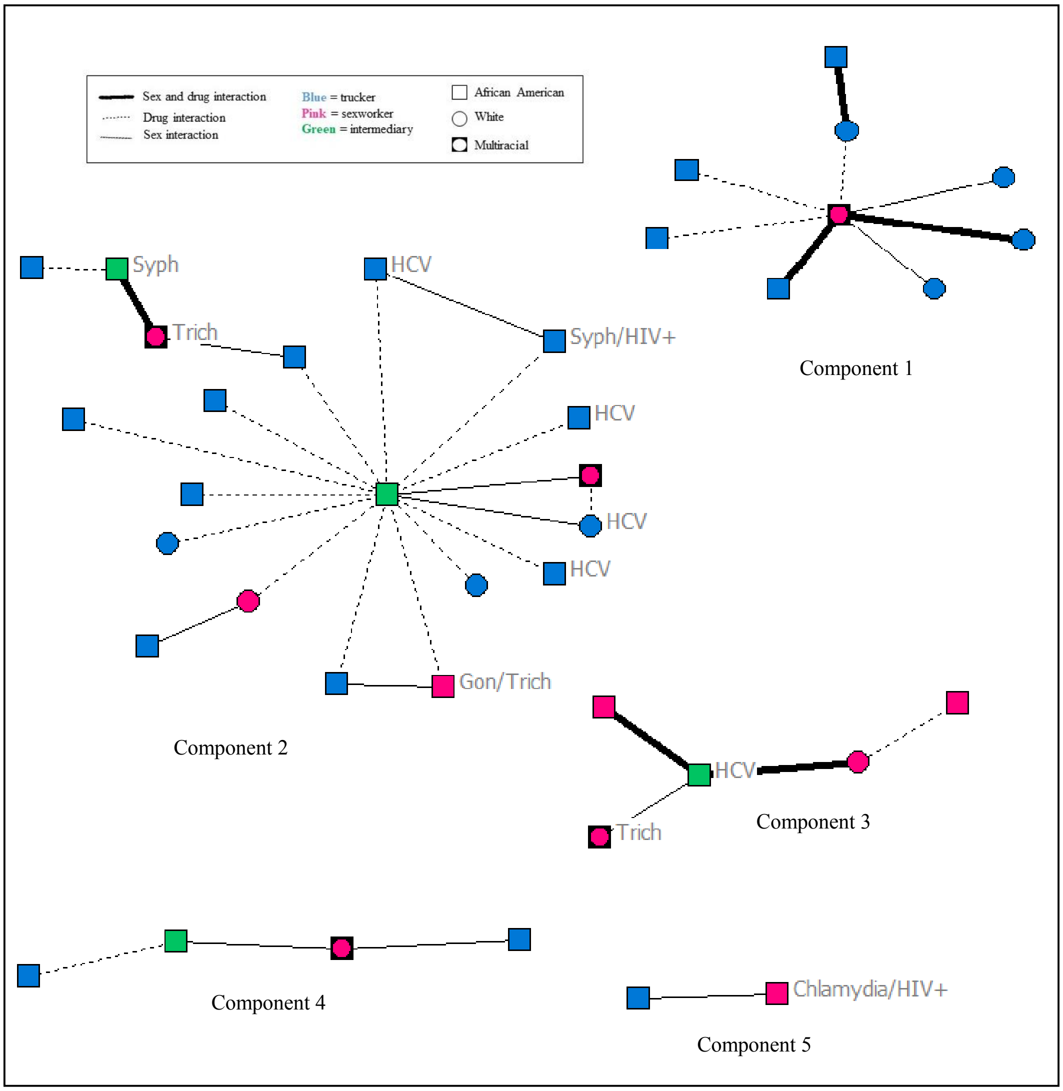
Figure 2
Moreland Cluster of Network Chains



disappearance/moving away, illnesses, or unforeseen travel yielded 88 individuals (58 long-haul truckers, 24 female sex workers, and 6 intermediaries) who participated in data collection.[21]

To be eligible to participate in interviews, female sex-workers had to be at least 18 years old, had sex for money with a trucker in the last month, agreed to provide a specimen for STI/BBI testing, and shared their sex and drug contacts with interviewer. Similarly, intermediaries were included if they were at least 18 years old, had sold drugs or pimped to truckers in the last month, agreed to specimen testing, and shared their sex and drug contacts. Lastly, truckers had to be male, at least 18 years old, used drugs or paid for sex while on the job in the last month, agreed to specimen collection, and shared their sex and drug contacts. More details on study design, sample recruitment, and participant protections can be found elsewhere.[20,21]

Figure 3
Fulton Cluster of Network Chains



During interviews, participants provided data on their: (1) role in the network (trucker, sex worker, or intermediary); (2) demographic information (age, race, sex, and sexual orientation); (3) sexual and substance-use behaviors; and (4) dyadic sexual partnerships and drug relationships. Figure 1 provides sample of questions used in interviews. For sexual behaviors, we asked participants to indicate anyone they had oral, anal, or vaginal sex with in the past 6 months. For substance-use behaviors, we asked participants about any substances, including alcohol, cigarettes, and illicit drugs, they were currently using or had used within the last 3 months. We asked interviewees if they did drugs with any of their sex contacts, and vice versa to identify multiplex relationships. Truckers confirmed relationships identified in index interviews when they were interviewed. We conducted interviews with all participants identified through RDS. Finally, at the conclusion of interviews, blood specimens were collected and tested for HIV, syphilis, HCV and HBV, while urine specimens and vaginal swabs were collected and tested for chlamydial infection, gonorrhea, herpes, and trichomoniasis for each participant. Serological analysis was performed at the medical laboratories of Emory University in Atlanta. Each interview lasted approximately one hour, and participants were given $40.00 at the conclusion of the interview.

We reviewed interview data to create relational edge lists (data files containing all dyadic relationships that exist between members of the network) and attribute files (data files detailing characteristics of each node in the network). We uploaded both data files into UCINET network software[27] and created network graphs that visually represent the connections present within the network, as well as characteristics of each node (eg, role in the network, STI/BBI status). As a result, we were able to: (1) determine the sex and drug behaviors and connections of network members; (2) map the relationships and interactions between and among network members and their consequences; and (3) illustrate the various network characteristics that lead to greater risk for infection and disease spread among trucker networks.

Data Analysis

We assessed structure of the networks and 5 key network properties in this analysis: multiplexity, assortative and disassortative mixing, concurrency, and bridging. Structure consisted of clusters and components. Clusters were groups of nodes from the same geographic location that had the opportunity to connect, and components are defined as a maximally connected subgraph of the network, with a set of points that are linked to one another through paths of any length.[23] We determined that multiplex relationships included both sex and drug exchanges between 2 people (indicated by thick, dark lines in the figures). Assortative mixing was based on connections between 2 people who both tested positive for infections. Disassortative mixing was identified when a person negative for an STI/BBI was connected with someone who tested positive. Concurrency was measured based on whether a person had multiple, overlapping sexual or drug ties in the network. Bridging was measured based on individuals being one path (ie, one connection) away from an infection. Using the network graphs generated in UCINET, we calculated the proportion of each network consistent of multiplex ties, proportion of nodes directly involved in a multiplex ties, proportion of nodes involved in concurrent ties, proportion of ties consistent of assortative and disassortative mixing, and proportion of nodes connected to a bridging node (eg, one path removed from another node).

RESULTS

Analyses revealed 2 clusters of network members (the Moreland Cluster and Fulton Boulevard Cluster, named for their geographic location), further broken down into 11 components of 88 individuals (58 male truckers, 24 female sex workers, and 6 male intermediaries; Figures 2 and 3). Of the 88 people included in the analysis, 24 tested positive for an STI/BBI (27.3%). The last column (called "Total") of Table 1 presents a detailed overview of the demographic, behavioral, and serological characteristics of all inner-city Atlanta trucker network members measured in this study.

Five of the 11 components consisted of people who had drug and sex exchanges (indicating multiplexity), ranging from 0%-37.5% of ties across components. Nearly 20% (18%) of nodes were involved in these multiplex relationships, and 21.6% were one connection away from a multiplex dyad. Nine of the 11 components had characteristics of disassortative mixing, with 29.5% of people who tested negative for an infection engaging in sex and/or drug exchanges with people who tested positive. Four of the 11 trucker-centered components (and 10.4% of total connections) contained assortative mixing, reaching as high as 25% of ties within components. Nine of the 11 components contained concurrency, and several concurrent relationships included someone who tested positive for at least one infection. Of the people involved in concurrent relationships, 41.7% tested positive for a STI/BBI in the Moreland cluster, and 47.1% in the Fulton cluster. Finally, 6 of the 11 components contained bridges, or nodes that connected a STI/BBI negative per-

Table 1
Sample Characteristics

	Moreland Avenue Cluster				Fulton Industrial Cluster				TOTAL
	Truckers	Sex workers	Intermediaries	Total	Truckers	Sex workers	Intermediaries	Total	
N (Recruited)	40	15	2	57	33	18	4	55	112
N (Interviewed)	35	11	2	48	23	13	4	40	88
Age in years (mean)	41.5 (SD=7.2)	34.7 (SD=6.7)	43 (SD=9.9)	40.0 (SD=7.6)	41 (SD=7.2)	37 (SD=5.5)	41.3 (SD=6.1)	39.7 (SD=6.7)	39.9 (SD=7.2)
Sex									
Men	35 (100%)	-	2 (100%)	37 (77.1%)	23 (100%)	-	4 (100%)	27 (67.5%)	64 (72.7%)
Women	-	11 (100%)	-	11 (22.9%)	-	13 (100%)	-	13 (32.5%)	24 (27.3%)
Race									
White	11 (31.4%)	5 (45.5%)	-	16 (33.3%)	6 (26.1%)	3 (23.1%)	-	9 (22.5%)	25 (28.4%)
African-American	19 (54.3%)	5 (45.5%)	1 (50%)	25 (52.1%)	17 (73.9%)	5 (38.5%)	4 (100%)	26 (65.0%)	51 (58.0%)
Multi-race	5 (14.3%)	1 (9.1%)	1 (50%)	7 (14.6%)	-	5 (38.5%)	-	5 (12.5%)	12 (13.6%)
Sexual Orientation									
Straight	34 (97.1%)	4 (36.4%)	1 (50%)	39 (81.3%)	21 (91.3%)	5 (38.5%)	3 (75%)	29 (72.5%)	68 (77.3%)
Bisexual	1 (2.9%)	6 (54.5%)	-	7 (14.6%)	2 (8.7%)	6 (46.2%)	-	8 (20%)	15 (17.0%)
Unknown	-	1 (9.1%)	1 (50%)	2 (4.2%)	-	2 (15.4%)	1 (25%)	3 (7.5)	5 (5.7%)
Substance Use									
Alcohol	5 (14.3%)	1 (9.1%)	-	6 (12.5%)	3 (13%)	3 (23.1%)	4 (100%)	10 (25%)	16 (18.2%)
Crack Cocaine	18 (51.4%)	9 (81.8%)	-	27 (56.3%)	13 (56.5%)	9 (69.2%)	2 (50%)	24 (60%)	51 (58.0%)
Powder Cocaine	5 (14.3%)	-	-	5 (10.4%)	4 (17.4%)	-	2 (50%)	6 (15%)	11 (12.5%)
Marijuana	1 (2.95)	1 (9.1%)	1 (50%)	3 (6.3%)	3 (13%)	1 (7.7%)	-	4 (10%)	7 (8%)
Methamphetamine (Speed)	2 (5.7%)	-	-	2 (4.2%)	1 (4.3%)	-	1 (25%)	2 (5%)	4 (4.5%)
STI/BBI Status									
HIV+	1 (2.9%)	1 (10%)	-	2 (4.2%)	1 (4.3%)	1 (7.7%)	-	2 (5%)	4 (4.5%)
HCV	3 (8.6%)	5 (45.5%)	1 (50%)	9 (18.8%)	4 (17.4%)	-	1 (25%)	5 (12.5%)	14 (15.9%)
HBV	1 (2.9%)	-	-	1 (2.1%)	-	-	-	-	1 (1.1%)
HSV2 (Herpes 1-2)	-	-	-	-	1 (4.3%)	-	-	1 (2.5%)	1 (1.1%)
Syphilis	1 (2.9%)	2 (18.2%)	-	3 (6.3%)	1 (4.3%)	-	1 (25%)	2 (5%)	5 (5.7%)
Trichomoniasis	-	-	-	-	-	3 (23.1%)	-	3 (7.5%)	3 (3.4%)
Chlamydia	1 (2.9%)	-	-	1 (2.1%)	-	1 (7.7%)	-	1 (2.5%)	2 (2.3%)
Gonorrhea	-	1 (9.1%)	-	1 (2.1%)	-	1 (7.7%)	-	1 (2.5%)	2 (2.3%)

Table 2
Network Properties for the Moreland Cluster of Network Chains

Network Property	Chain 1	Chain 2	Chain 3	Chain 4	Chain 5	Chain 6	Overall
Multiplexity							
% of multiplex ties	0%	30%	8.3%	0%	0%	0%	10.3%
% of nodes directly involved in a multiplex tie	0%	36.4%	15.4%	0%	0%	0%	13.3%
Assortative Mixing							
% of ties between two STI/BBI positive people	18.2%	30%	0%	0%	0%	0%	12.8%
Disassortative Mixing							
% of ties between a STI/BBI positive person and STI/BBI negative person	36.4%	70%	16.7%	66.7%	100%	100%	46.2%
Concurrency							
% of nodes having more than one tie	33.3%	9.1%	30.8%	50%	33.3%	0%	26.7%
% of nodes that have more than one tie who are STI/BBI positive	50%	100%	0%	50%	100%	0%	41.7%
Bridging							
% of nodes one path removed from a STI/BBI	75%	90.9%	61.5%	25%	0%	0%	62.2%

son with a STI/BBI positive person. This resulted in 62.2% of nodes in the Moreland cluster and 47.5% of nodes from the Fulton cluster one path (ie, one connection) removed from an infection. Tables 2 and 3 summarize the network properties across clusters.

Table 3
Network Properties for the Fulton Cluster of Network Chains

Network Property	Chain 1	Chain 2	Chain 3	Chain 4	Chain 5	Overall
Multiplexity						
% of multiplex ties	37.5%	4.5%	50%	0%	0%	15.8%
% of nodes directly involved in a multiplex tie	55.6%	10%	60%	0%	0%	25%
Assortative Mixing						
% of ties between 2 STI/BBI positive people	0%	9.1%	25%	0%	0%	7.9%
Disassortative Mixing						
% of ties between a STI/BBI positive person and a STI/BBI negative person	0%	40.9%	50%	0%	100%	31.6%
Concurrency						
% of nodes having more than one tie	22.2%	55%	40%	50%	0%	44.7%
% of nodes that have more than one tie who are STI/BBI positive	0%	54.5%	50%	0%	0%	47.1%
Bridging						
% of nodes one path removed from a STI/BBI	0%	80%	60%	0%	0%	47.5%

DISCUSSION

The purpose of this study was to examine network properties among a group of truckers, sex workers, and intermediaries in relation to STI/BBI disease risk. Similar to previous research, our results demonstrate that network structures could increase risk of disease spread through sexual and drug interactions.

Several of the relationships mapped were multiplex, indicating the existence of more than one type of relationship (ie, sex and drug exchanges) within a dyad.[28] For example, in Figure 2 *(Moreland Avenue Component 2),* the index (who tested positive for HCV) had multiplex relationships with 3 truckers; thus, chances of HCV spread to those directly connected to the index increase due to new opportunities for bodily fluid exchange. Furthermore, the index has a multiplex relationship with a trucker who tested positive for syphilis; not only does the index's risk increase, but anyone connected to her is now at greater risk of contracting syphilis based on her multiplex relationship. Multiplexity has implications on HIV/AIDS and STI transmission for both men and women; women might be at higher risk for HIV due to overlapping relationships considered to be risky, and men might connect with women that have increased exposure to infection due to multiplexity.[15] Previous research exploring multiplexity within persons at greater risk for HIV transmission (eg, sex workers, intravenous drug users) reported greater rates of multiplexity than the present study (21%-53%), and found a higher likelihood of multiplexity among people with more connections within persons of the same race, sexual orientation, and those with more network ties.[15,29] Our study identified similar patterns of multiplexity, particularly among those most densely connected in the network.

Although the drugs most widely used within these networks do not involve a syringe or intravenous injection that would increase BBI transmission risk, drug use in general increases partaking in risky behaviors, including unprotected sex.[30,31] Drug use can result in reducing inhibitions and negatively affecting one's judgment, which could mean inconsistent condom use and other safer sex practices with partners that partake in multiplex relationships. Thus, multiplexity is not only a matter of exacerbating exposure to infection through needle sharing and unprotected sex, but also the 2 behaviors can converge to increase disease burden exponentially.[32]

Disassortative mixing can introduce infections to new groups of people across networks, and therefore, helps to maximize epidemics over long periods of time, especially in transient populations like long-haul truck drivers.[16] In this case, 29.5% of people who tested negative for an infection engaged in sex and/or drug exchanges with people who tested positive, increasing their risk of infection, and in turn, transmission to other contacts. For example, in Figure 3 *(Fulton Boulevard Component* 2), the female sex worker index who tested negative for STIs/BBIs is connected directly to 6 people with various STIs/BBIs, and is also connected to 3 other STI/BBI negative people that are directly tied to someone who tested positive. Not only does her risk increase through disassortative mixing, but others she engages with also face increased risk.

Contrarily, assortative mixing can prolong epidemics, and therefore, increases risk longevity.[33] *Moreland Avenue Component 1* (Figure 2) illustrates 2 people connected that both tested positive for HCV. Their combined 5 direct contacts, and the subsequent 5 people they are indirectly connected to, are at heightened risk for HCV. Studies suggest assortative mixing generates rapid increases in incidence of an infection in the early stages of an epidemic, specifically within highly assortative groups,[4] while high disassortative mixing can maximize an epidemic over long periods of time by introducing the infection to new subgroups of the population. Additionally, high assortative mixing can produce drawn out epidemics with multiple peaks.[16,33] Therefore, these networks are both vulnerable to increased disease endemicity and longevity due to assortative and disassortative mixing. These findings align with previous research suggesting mixing can augment disease risk, particularly STI/BBI risk between people who engage in sex and drug exchanges.[18,34]

Several people across network components had multiple partners (concurrency), which amplifies risk of disease spread across network.[17] For example, in *Moreland Avenue Component 5 (Figure 2),* a sex worker who tested positive for gonorrhea was connected to 2 truckers; with each new partner, the risk for gonorrhea grows. Concurrency influences the speed of the initial phase of an epidemic, as well as the number of infected individuals over time.[35] Concurrent partnerships increase the likelihood of exposure to infected persons and as a result, serve as a risk for infection acquisition and spread.[18] Furthermore, individuals with multiple partners represent heightened risk points within networks, as they often serve to bridge sections of networks and impact larger partitions of networks.[17] Previous research highlights the risk of concurrent relationships, with studies reporting similar rates of concurrency between 39% and 54% among high risk networks (eg, men who have sex with men).[34,36]

Whereas bridging does not necessarily put someone in direct connection with risk, it does serve as a mechanism to link those who would otherwise be at lower risk with people at higher risk. In this case, although disassortative mixing directly connected someone who was negative for infection to someone with an infection, bridging creates secondary risk by more closely associating STI/BBI negative people with STI/BBI positive people; therefore, individual nodes become "bridges" for infection to cross over. Bridging nodes, sometimes referred to as liaisons, describe people who connect network members at a low risk for disease, such as HIV, with members who present a high risk.[37] For example, in *Moreland Avenue Component* 3 (Figure 2), 6 people who tested negative for an infection were connected to a sex worker, who in turn was directly connected to someone with HBV – the sex worker now serves as a bridge between her 6 connections and HBV. Bridging is a mechanism for expediting disease spread, especially to various subgroups within networks.[38] Bridging is often a product of disassortative mixing and concurrency, with disassortative mixing serving as a social bridge (creating new connections across a network based on various traits), and concurrency operating as a temporal bridge (connections, and subsequently disease spread, occur at certain points in time).[18] Overall, the network structures present within these network chains likely impact the spread of infection through social ties.

Limitations

The cross-sectional nature of data and participant attrition comprise the 2 key limitations of this study. The use of a longitudinal design would provide a more accurate representation of the extent to which network characteristics (eg, mixing, concurrency) can exacerbate infection spread. Furthermore, based on many features of this population cohort (transience, incarceration, incapacitation), networks tend to change over time. Thus, this study provides an illustration of how social network structure may induce risk for disease at a specific point in time.

Suggestions for Future Practice

These data serve as an important first step in possible future programming to combat disease spread among this population. Valente et al[39] presented a 4-stage model for using network data for successful program implementation. The first stage (exploration and needs assessment) requires the collection of network data in a community to determine: (1) how the network is patterned/structured, (2) key people that could facilitate change in the network (eg, opinion leaders, bridge-builders), and (3) associations between individual characteristics of interest and network properties. Our study provides this key information that could then inform stages 2-4 (program design, implementation, and sustainment/monitoring), which would result in a network-informed strategy to reduce STI/BBI transmission and spread. Using network data to inform strategies often lead to better health-related outcomes and more successful interventions compared to those who do not use network data.[39,40]

Conclusion

The social networks truckers engage in within inner-city locales, particularly for drug and sex exchanges, present a heightened risk for STI/BBI spread. In this study. we illustrated how network characteristics may amplify risks of disease spread across trucker-centered networks, especially through multiplexity, assortative and disassortative mixing, concurrency, and bridging.

Human Subjects Approval Statement

All study procedures received approval by the Institutional Review Board of Emory University (#781-2012), and participants provided their informed consent prior to data collection.

Conflict of Interest Statement

The authors declare no conflicts of interest.

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References

1. Keeling MJ, Eames KTD. Networks and epidemic models. *J R Soc Interface*. 2005;2(4):295-307. doi:10.1098/rsif.2005.0051
2. Rothenberg RB, Dai D, Adams MA, Heath JW. The HIV endemic: maintaining disease transmission in at-risk urban areas. *Sex Transm Dis*. 2017;44(2):71-78. doi:10.1097/OLQ.0000000000000561
3. Morris M. Epidemiology and social networks: modeling structured diffusion. *Sociol Methods Res*. 1993;22(1):99-126. doi:10.1177/0049124193022001005
4. Rothenberg RB. How a net works: implications of network structure for the persistence and control of sexually transmitted diseases and HIV. *Sex Transm Dis*. 2001;28(2):63-68. doi:10.1097/00007435-200102000-00001
5. Sastry S. Long distance truck drivers and the sructural context of health: a culture-centered investigation of Indian truckers' health narratives. *Health Commun*. 2016;31(2):230-241. doi:10.1080/10410236.2014.947466
6. Apostolopoulos Y, Sönmez S, Shattell M, Belzer MH. Environmental determinants of obesity-associated morbidity risks for truckers. *Int J Workplace Health Manag*. 2012;5(2):120-138. doi:10.1108/17538351211239162
7. Scribner RA, Johnson SA, Cohen DA, et al. Geospatial methods for identification of core groups for HIV/AIDS. *Subst Use Misuse*. 2008;43(2):203-221. doi:10.1080/10826080701690607
8. Gesink DC, Sullivan AB, Norwood T, et al. Does core area theory apply to STIs in rural environments? *Sex Transm Dis*. 2013;40(1):32-40. doi:10.1097/OLQ.0b013e3182762524
9. Martinez AN, Mobley LR, Lorvick J, et al. Spatial analysis of HIV positive injection drug users in San Francisco, 1987 to 2005. *Int J Environ Res Public Health*. 2014;11(4):3937-3955. doi:10.3390/ijerph110403937
10. Idoiaga N, Gil de Montes L, Asla N, Larrañaga M. Where does risk lie in sexual practices? A study of young people's social representations. *Health Risk Soc*. 2020;20(3-4):249-265. doi:10.1080/13698575.2020.1793304
11. Skidmore D, Hayter E. Risk and sex: ego-centricity and sexual behaviour in young adults. *Health Risk Soc*. 2000;2(1):23-32. doi:10.1080/136985700111422
12. Emch M, Root ED, Giebultowicz S, et al. Integration of spatial and social network analysis in disease transmission studies. *Ann Assoc Am Geogr*. 2012;105(5):1004-1015. doi:10.1080/00045608.2012.671129
13. Potterat J, Rothenberg RB, Muth SQ. Network structural dynamics and infectious disease propagation. *Int J STD AIDS*. 1999;10(3):182-185. doi:10.1258/0956462991913853
14. Valente TW, Vlahov D. Selective risk taking among needle exchange participants: implications for supplemental interventions. *Am J Public Health*. 2001;91(3):406-411. doi:10.2105/ajph.91.3.406
15. Rudolph AE, Crawford ND, Latkin CA, Lewis CF. Multiplex relationships and HIV: implications for network-based interventions. *AIDS Behav*. 2017;21(4):1219-1227. doi:10.1007/s10461-016-1454-2
16. Gupta S, Anderson RM, May RM. Networks of sexual contacts: implications for the pattern of spread of HIV. *AIDS*. 1989;3(12):807-817.
17. Morris M. *Network Epidemiology: A Handbook for Survey Design and Data Collection*. Oxford, UK: Oxford University Press; 2004.
18. Doherty IA, Shiboski S, Ellen JM, et al. Sexual bridging socially and over time: a simulation model exploring the relative effects of mixing and concurrency on viral sexually transmitted infection transmission. *Sex Transm Dis*. 2006;33(6):368-373. doi:10.1097/01.olq.0000194586.66409.7a
19. Chen NE, Strathdee SA, Uribe-Salas FJ, et al. Correlates of STI symptoms among female sex workers with truck driver clients in two Mexican border towns. *BMC Public Health*. 2012;12(1):1000. doi:10.1186/1471-2458-12-1000
20. Apostolopoulos Y, Sönmez S, Lemke MK, Rothenberg RB. Mapping U.S. long-haul truck drivers' multiplex networks and risk topography in inner-city neighborhoods. *Health Place*. 2015;34:9-18. doi:10.1016/j.healthplace.2015.03.008
21. Sönmez S, Apostolopoulos Y, Tanner AE, et al. Ethno-epidemiological research challenges: networks of long-haul truckers in the inner city. *Ethnography*. 2016;17(1):111-134. doi:org/10.1177/1466138115597703
22. Heckathorn D. Respondent-driven sampling: a new approach to the study of hidden populations. *Soc Probl*. 1997;44(2):174-199. doi:org/10.2307/3096941
23. Valente TW. *Social Networks and Health: Models, Methods, and Applications*. Oxford, UK: University Press; 2010.
24. Apostolopoulos Y, Sönmez S. Tracing the diffusion of infectious diseases in the transport sector. In Apostolopoulos Y, Sönmez S, eds. *Population Mobility and Infectious Disease*. New York, NY: Springer; 2007:131-156.
25. Heckathorn DD, Semaan S, Broadhead RS, Hughes JJ. Extensions of respondent-driven sampling: a new approach to the study of injection drug users aged 18-25. *AIDS Behav*. 2002;6(1):55-67. doi:10.1023/A:1014528612685
26. Magnani R, Sabin K, Saidel T, Heckathorn D. Review of sampling hard-to-reach and hidden populations for HIV surveillance: *AIDS*. 2005;19(Suppl 2):S67-S72. doi:10.1097/01.aids.0000172879.20628.e1
27. Borgatti SP, Everett MG, Freeman LC. *UCINET for Windows: Software for Social Network Analysis*. Nicholasville, KY: Analytic Technologies; 2002.
28. Scott S, Carrington PJ. *The SAGE Handbook of Social Network Analysis*. Thousand Oaks, CA: Sage Publications; 2011.
29. Felsher M, Koku E. Explaining HIV risk multiplexity: a

social network analysis. *AIDS Behav*. 2018;22(11):3500-3507. doi:10.1007/s10461-018-2120-7
30. Mutchler MG, McKay T, Candelario N, et al. Sex drugs, peer connections, and HIV: use and risk among African American, Latino, and Multiracial young men who have sex with men (YMSM) in Los Angeles and New York. *J Gay Lesbian Soc Serv*. 2011;23(2):271-295. doi:10.1080/10538720.2011.560100
31. Weinstock HS, Lindan C, Bolan G, et al. Factors associated with condom use in a high-risk heterosexual population. *Sex Transm Dis*. 1993;20(1):14-20.
32. Wilson PA, Nanin J, Amesty S, et al. Using syndemic theory to understand vulnerability to HIV infection among Black and Latino men in New York City. *J Urban Health Bull N Y Acad Med*. 2014;91(5):983-998. doi:10.1007/s11524-014-9895-2
33. Raymond HF, McFarland W. Racial mixing and HIV risk among men who have sex with men. *AIDS Behav*. 2009;13(4):630-637. doi:10.1007/s10461-009-9574-6
34. Li J, Luo J, Li J, Liu H. Disassortative mixing patterns of drug-using and sex networks on HIV risk behaviour among young drug users in Yunnan, China. *Public Health*. 2015;129(9):1237-1243. doi:10.1016/j.puhe.2015.07.020
35. Kretzschmar M, Morris M. Measures of concurrency in networks and the spread of infectious disease. *Math Biosci*. 1996;133(2):165-195.
36. Pines HA, Wertheim JO, Liu L, et al. Concurrency and HIV transmission network characteristics among MSM with recent HIV infection. *AIDS*. 2016;30(18):2875-2883. doi:10.1097/QAD.0000000000001256
37. Williams ML, Atkinson J, Klovdahl A, et al. Spatial bridging in a network of drug-using male sex workers. *J Urban Health Bull N Y Acad Med*. 2005;82(Suppl 1):i35-i42. doi:10.1093/jurban/jti022
38. Morris M, Podhisita C, Wawer MJ, Handcock MS. Bridge populations in the spread of HIV/AIDS in Thailand. *AIDS*. 1996;10(11):1265-1271. doi:10.1097/00002030-199609000-00013
39. Valente TW, Palinkas LA, Czaja S, et al. Social network analysis for program implementation. *PLoS One*. 2015;10(6):e0131712. doi:10.1371/journal.pone.0131712
40. Valente TW. Network interventions. *Science*. 2012;337(6090):49-53. doi:10.1126/science.1217330