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Using Network Analysis to Explore the Implementation & Impact of Population Health Strategies

Glen P. Mays, University of Kentucky

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Glen Mays, PhD, MPH
University of Kentucky

glen.mays@uky.edu
systemsforaction.org

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Acknowledgements

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- Collaborators include Cezar Mamaril, Rachel Hogg, Rick Ingram
Using networks for population health improvement strategies

- Designed to achieve large-scale health improvement: neighborhood, city/county, region
- Target fundamental and often multiple determinants of health
- Mobilize the collective actions of multiple stakeholders in government & private sector

Using networks to overcome collective action problems

- Incentive compatibility → public goods
- Concentrated costs & diffuse benefits
- Time lags: costs vs. improvements
- Uncertainties about what works
- Asymmetry in information
- Difficulties measuring progress
- Weak and variable institutions & infrastructure
- Imbalance: resources vs. needs
- Stability & sustainability of funding

Ostrom E. 1994
Research questions of interest

- Which organizations engage in implementation of population health activities in local communities?
- How and why do these contributions change over time?
- How do patterns of interaction influence volume, scope, and effectiveness of pop health activities?
  - Complementarities/Synergies
  - Substitutions
  - Crowd-out
Data: networks for population health

National Longitudinal Survey of Public Health Systems

- Cohort of 360 communities with at least 100,000 residents
- Local public health officials report:
  - **Scope**: availability of 20 recommended population health activities
  - **Network**: types of organizations contributing to each activity
  - **Perceived effectiveness** of each activity in meeting community needs

** Stratified sample of 500 communities with <100,000 residents added beginning in 2014 wave
Measures: recommended capabilities that support implementation of multi-sector health initiatives

Foundational Capabilities

- Engage stakeholders
- Assess needs & risks
- Identify evidence-based actions
- Develop shared priorities & plans
- Commit shared resources & responsibilities
- Coordinate Implementation
- Monitor, evaluate, feedback

Network analytic approach

Two-mode networks (organization types X activities) transformed to one-mode networks with tie strength indicated by number of activities jointly produced.

<table>
<thead>
<tr>
<th>Organization Type/Sector</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3   4  5  6  7  ...20</td>
</tr>
<tr>
<td>Local public health agency</td>
<td>X  X  X   X  X  X</td>
</tr>
<tr>
<td>State public health agency</td>
<td>X  X  X   X  X  X</td>
</tr>
<tr>
<td>Hospitals</td>
<td>X  X  X   X  X  X</td>
</tr>
<tr>
<td>Physician practices</td>
<td></td>
</tr>
<tr>
<td>CHCs</td>
<td>X  X  X   X  X  X</td>
</tr>
<tr>
<td>Insurers</td>
<td></td>
</tr>
<tr>
<td>Employers</td>
<td></td>
</tr>
<tr>
<td>Social service organizations</td>
<td>X  X  X   X  X  X</td>
</tr>
<tr>
<td>Schools</td>
<td></td>
</tr>
<tr>
<td>.....</td>
<td></td>
</tr>
</tbody>
</table>
Data linkages expand analytic possibilities

- **Area Health Resource File**: health resources, demographics, socioeconomic status, insurance coverage
- **NACCHO Profile data**: public health agency institutional and financial characteristics
- **CMS Impact File & Cost Report**: hospital ownership, market share, uncompensated care
- **Dartmouth Atlas**: Area-level medical spending (Medicare)
- **CDC Compressed Mortality File**: Cause-specific death rates by county
- **Equality of Opportunity Project (Chetty)**: local estimates of life expectancy by income
- **National Health Interview Survey**: individual-level health
- **HCUP**: area-level hospital and ED use, readmissions
Cluster and network analysis to identify “system capital”

Cluster analysis is used to classify communities into one of 7 categories of population health system capital based on:

- **Scope of activities** contributed by each type of organization
- **Density of connections** among organizations jointly producing activities
- **Degree centrality** of organizational contributors

Average network structure in 2016

Node size = degree centrality

Line size = % activities jointly contributed (tie strength)
Network density and scope of activities

Comprehensive System Capital

Mays GP et al. *Health Affairs* 2016
Variation and change in prevalence of comprehensive system capital
Variation in network structure in 2016

- Network Density: 14.1x
- Network Centrality: 2.6x
- Hospital Centrality: 7.6x
- Employer Centrality: 29.2x
## Organizational contributions to population health activities

<table>
<thead>
<tr>
<th>Type of Organization</th>
<th>1998</th>
<th>2016</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local public health agencies</td>
<td>60.7%</td>
<td>67.5%</td>
<td>11.1%</td>
</tr>
<tr>
<td>Other local government agencies</td>
<td>31.8%</td>
<td>33.2%</td>
<td>4.4%</td>
</tr>
<tr>
<td>State public health agencies</td>
<td>46.0%</td>
<td>34.3%</td>
<td>-25.4%</td>
</tr>
<tr>
<td>Other state government agencies</td>
<td>17.2%</td>
<td>12.3%</td>
<td>-28.8%</td>
</tr>
<tr>
<td>Federal government agencies</td>
<td>7.0%</td>
<td>7.2%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>37.3%</td>
<td>46.6%</td>
<td>24.7%</td>
</tr>
<tr>
<td>Physician practices</td>
<td>20.2%</td>
<td>18.0%</td>
<td>-10.6%</td>
</tr>
<tr>
<td>Community health centers</td>
<td>12.4%</td>
<td>29.0%</td>
<td>134.6%</td>
</tr>
<tr>
<td>Health insurers</td>
<td>8.6%</td>
<td>10.6%</td>
<td>23.0%</td>
</tr>
<tr>
<td>Employers/businesses</td>
<td>16.9%</td>
<td>15.3%</td>
<td>-9.6%</td>
</tr>
<tr>
<td>Schools</td>
<td>30.7%</td>
<td>25.2%</td>
<td>-17.9%</td>
</tr>
<tr>
<td>Universities/colleges</td>
<td>15.6%</td>
<td>22.6%</td>
<td>44.7%</td>
</tr>
<tr>
<td>Faith-based organizations</td>
<td>19.2%</td>
<td>17.5%</td>
<td>-9.1%</td>
</tr>
<tr>
<td>Other nonprofit organizations</td>
<td>31.9%</td>
<td>32.5%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Other</td>
<td>8.5%</td>
<td>5.2%</td>
<td>-38.4%</td>
</tr>
</tbody>
</table>
Bridging capital in population health networks: Trends in betweenness centrality

* Change from prior years is statistically significant at p<0.05

* 2016
## Changes in Tie Strength: 1998-2016

<table>
<thead>
<tr>
<th></th>
<th>Local Public Health</th>
<th>State Government</th>
<th>Local Government</th>
<th>Federal Government</th>
<th>Physicians</th>
<th>Hospitals</th>
<th>CHCs</th>
<th>Faith-Based</th>
<th>Other Nonprofits</th>
<th>Health Insurers</th>
<th>Employers</th>
<th>Schools</th>
<th>Universities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local public health</td>
<td>-4.9%</td>
<td>4.6%</td>
<td>-3.4%</td>
<td>-13.0%</td>
<td>24.1%</td>
<td>130.6%</td>
<td>-12.8%</td>
<td>9.2%</td>
<td>22.0%</td>
<td>-13.8%</td>
<td>83.8%</td>
<td>47.4%</td>
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</tr>
<tr>
<td>State government</td>
<td>-14.8%</td>
<td>2.3%</td>
<td>-19.8%</td>
<td>2.6%</td>
<td>81.8%</td>
<td>-26.5%</td>
<td>-11.2%</td>
<td>8.6%</td>
<td>31.2%</td>
<td>81.0%</td>
<td>18.0%</td>
<td></td>
<td></td>
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<tr>
<td>Local government</td>
<td></td>
<td>-11.0%</td>
<td>13.8%</td>
<td>117.8%</td>
<td>-16.5%</td>
<td>7.1%</td>
<td>17.2%</td>
<td>-16.6%</td>
<td>136.4%</td>
<td>51.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Federal government</td>
<td>-11.7%</td>
<td>5.6%</td>
<td>-11.0%</td>
<td>13.8%</td>
<td>2.4%</td>
<td>82.4%</td>
<td>-38.1%</td>
<td>2.4%</td>
<td>24.2%</td>
<td>-47.6%</td>
<td>126.7%</td>
<td>-0.8%</td>
<td></td>
</tr>
<tr>
<td>Physicians</td>
<td>-8.8%</td>
<td>2.4%</td>
<td></td>
<td>2.4%</td>
<td>57.9%</td>
<td>-21.2%</td>
<td>-12.8%</td>
<td>5.1%</td>
<td>-22.6%</td>
<td>122.1%</td>
<td>35.3%</td>
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<td></td>
</tr>
<tr>
<td>Hospitals</td>
<td>142.4%</td>
<td>-10.1%</td>
<td>11.3%</td>
<td>29.5%</td>
<td>10.4%</td>
<td>141.5%</td>
<td>55.4%</td>
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<tr>
<td>CHCs</td>
<td>-10.7%</td>
<td>115.8%</td>
<td>103.7%</td>
<td>-8.4%</td>
<td>411.0%</td>
<td>172.5%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Faith-based organizations</td>
<td>-12.4%</td>
<td>-8.8%</td>
<td>-8.0%</td>
<td>-7.7%</td>
<td>0.4%</td>
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<td></td>
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<tr>
<td>Other nonprofits</td>
<td>17.6%</td>
<td>-9.2%</td>
<td>148.0%</td>
<td>53.8%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Health insurers</td>
<td>-4.6%</td>
<td>240.1%</td>
<td>57.7%</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Employers</td>
<td>-15.7%</td>
<td>-6.7%</td>
<td></td>
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</tr>
<tr>
<td>Schools</td>
<td>288.0%</td>
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</tbody>
</table>
Estimating network effects

**Dependent variables:**

- **Scope**: Percent of population activities implemented
- **Quality**: Perceived effectiveness of activities
- **Resource use**: Local public health spending; Area-level Medicare spending
- **Health outcomes**: premature mortality(<75), infant mortality, death rates for heart disease, diabetes, cancer, influenza

**Independent variables:**

- **Contribution scores**: percent of activities contributed by each type of organization
- **Network characteristics**: network density, organizational degree centrality, betweenness centrality
- **Composite network measure**: comprehensive system capital
Estimating network effects

Estimation:

- Log-transformed Generalized Linear Latent and Mixed Models
- Account for repeated measures and clustering of communities within states
- Instrumental variables address endogeneity of network structures

\[
\ln(\text{Network}_{z,ijt}) = \sum \alpha_{z}\text{Governance}_{ijt} + \beta_1\text{Agency}_{ijt} + \beta_2\text{Community}_{ijt} + \mu_j + \phi_t + \varepsilon_{ijt}
\]

\[
\ln(\text{Quantity/Quality/Cost}_{ijt}) = \sum \alpha_{z}\ln(\hat{\text{Network}}_{z})_{ijt} + \beta_1\text{Agency}_{ijt} + \beta_2\text{Community}_{ijt} + \mu_j + \phi_t + \varepsilon_{ijt}
\]

All models control for type of jurisdiction, population size and density, metropolitan area designation, income per capita, unemployment, racial composition, age distribution, educational attainment, and physician availability.
Health effects attributable to network structures

Models also control for racial composition, unemployment, health insurance coverage, educational attainment, age composition, and state and year fixed effects.

N=1019 community-years

Mays GP et al. Health Affairs 2016
Economic effects attributable to network structure

Impact of Comprehensive Systems on Medical Spending (Medicare)

Models also control for racial composition, unemployment, health insurance coverage, educational attainment, age composition, and state and year fixed effects. N=1019 community-years. Vertical lines are 95% confidence intervals.

Mays GP et al. Health Services Research 2017
Equity effects attributable to network structure

Impact of Comprehensive Systems on Life Expectancy by Income

Models also control for racial composition, unemployment, health insurance coverage, educational attainment, age composition, and state and year fixed effects. N=1019 community-years. Vertical lines are 95% confidence intervals.

Mays GP et al. forthcoming
Some conclusions

- Population health activities are produced through highly inter-organizational and multi-sectoral efforts (62% of contributions from outside governmental public health sector).
- Structure of population health networks varies widely and changes over time.
- Structure appears closely related to performance & outcomes.
- Network structure is endogenous – ignoring this can lead to biased estimates of impact.
Caveats: methodological trade-offs in systems science

In order to follow large numbers of community networks over long periods of time:

- Single respondent in each community
- Low-resolution measures of population health activities
- Networks defined by organization types/sectors, not individual organizations
Testing mechanisms for aligning medical, social, and public health systems
For More Information

Systems for Action
National Coordinating Center
Systems and Services Research to Build a Culture of Health

Supported by The Robert Wood Johnson Foundation

Glen P. Mays, Ph.D., M.P.H.
glen.mays@uky.edu
@GlenMays

Email: systemsforaction@uky.edu
Web: www.systemsforaction.org
     www.publichealthsystems.org
Journal: www.FrontiersinPHSSR.org
Archive: works.bepress.com/glen_mays
Blog: publichealththeconomics.org
Appendix: Ancillary Results
## Determinants of system structure

### Probit Estimates of Factors Influencing the Probability of Comprehensive System Capital

<table>
<thead>
<tr>
<th>Variable</th>
<th>Marginal Effect on Probability of System Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local board of health with decentralized governance</td>
<td>14.2%**</td>
</tr>
<tr>
<td>Local board of health with centralized governance</td>
<td>9.7%**</td>
</tr>
<tr>
<td>Centralized governance without local board of health</td>
<td>-4.5%**</td>
</tr>
<tr>
<td>Decentralized governance without local board of health</td>
<td>Reference</td>
</tr>
<tr>
<td>Population size (100,000s)</td>
<td>4.2%**</td>
</tr>
<tr>
<td>Population density (1000s)</td>
<td>4.9%*</td>
</tr>
<tr>
<td>Household income per capita (1000s)</td>
<td>2.5%**</td>
</tr>
</tbody>
</table>

Models also control for racial composition, unemployment, health insurance coverage, educational attainment, age composition, and state and year fixed effects. N=779 community-years  **p<0.05   *p<0.10
Do other organizations complement or substitute for public health agency work?

Results from Multivariate GLLAMM Models
How does organizational centrality affect the scope of population health activities?

Results from Multivariate GLLAMM Models